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ABSTRACT

This technical specialty course is one of thirty-five courses designed for use by two-year postsecondary institutions in five nuclear technician curriculum areas: (1) radiation protection technician, (2) nuclear instrumentation and control technician, (3) nuclear materials processing technician, (4) nuclear quality-assurance/quality-control technician, and (5) nuclear reactor (plant) operator trainee. This course, Nondestructive Examination Techniques I, contains seven modules: Visual Tests, Leak Tests, Hydrostatic Tests, Liquid Penetrant, Fundamentals of Radiography, Radiograph Inspection, and Radiographic Specifications and Code Requirements. Each module follows a typical format including the following sections: introduction, module prerequisites, objectives, subject matter, exercises, materials, procedures, data tables, reference materials, and tests. (A master index and suggested program planning guides are also available--see CE 026 856 and CE 026 639-643.) (LRA)

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Nuclear Technology Series

COURSE 26

NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES I

CENTER FOR OCCUPATIONAL RESEARCH
AND DEVELOPMENT, INC.
4800 LAKEWOOD DRIVE
WACO, TEXAS 76710

JUN 1980

U.S. DEPARTMENT OF HEALTH,
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PREFACE

ABOUT NUCLEAR TECHNOLOGY MODULES

The modules - developed by TERC-SW for use in two-year postsecondary technical institutions to prepare technicians for employment - are useful in industry for updating employees in company-sponsored training, and as laboratory texts in engineering schools. The principles, techniques and skills taught in the modules, based on tasks that nuclear technicians perform, were obtained from a nationwide advisory committee of employers of nuclear technicians. Each module was written by a working technical expert/experienced writer team and tested with students.

A module contains the following elements:

Introduction, which identifies the topic and often includes a rationale for studying the material.

Module Prerequisites, which identify the material a student should be familiar with before studying the module.

Objectives, which clearly identify what the student is expected to know for satisfactory module completion. The objectives, stated in terms of action-oriented behaviors, include such action words as operate, measure, calculate, identify and define, rather than words with many interpretations, such as know, understand, learn and appreciate.

Subject Matter, which presents the background theory and techniques supportive to the objectives of the module. Subject matter is written with the technical student in mind.

Exercises, which provide practical problems to which the student can apply this new knowledge.

Materials, which identify the equipment required to complete the laboratory procedure.

Procedures, which is the experiment section, or "hands-on" portion of the module (including step-by-step instruction) designed to reinforce student learning.

Data Tables, which are included in most modules for the first year (or basic) courses to help the student learn how to collect and organize data.

Reference Materials, which are included as suggestions for supplementary reading/viewing for the student.

Test, which measures the student's achievement of the prestated objectives.

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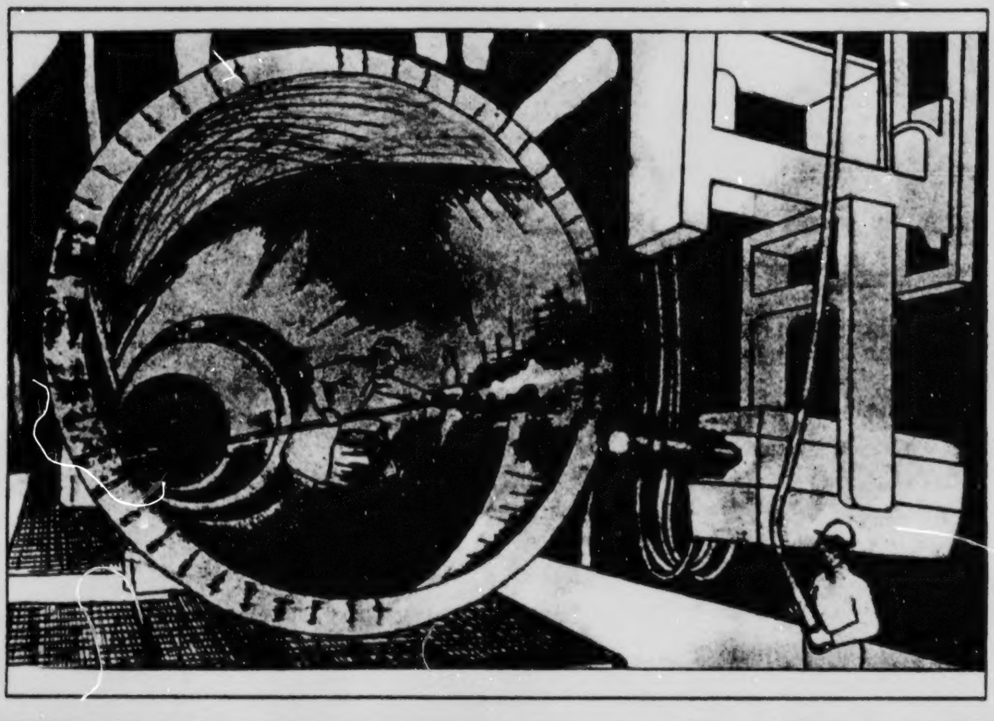
Module 26-6	Radiograph Inspection
Module 26-7	Radiographic Specifications and Code Requirements

NUCLEAR TECHNOLOGY

MODULE 26 - 1

VISUAL TESTS



COURSE 26: NONDESTRUCTIVE EXAMINATION (NDE)

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
4800 LAKEWOOD DRIVE WACO, TEXAS

COURSE 26 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES I

⇨ MODULE 26-1	Visual Tests
MODULE 26-2	Leak Tests
MODULE 26-3	Hydrostatic Tests
MODULE 26-4	Liquid Penetrant
MODULE 26-5	Fundamentals of Radiography
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INTRODUCTION

Visual examinations are widely used throughout industry. They comprise some of the most important of all product examinations. Many product characteristics are accepted based solely on visual examination and most other types of examinations employ visual examination to some extent.

Contrary to first appearance, visual examination is not particularly simple. When visual examining an item, what does one see? What should one look for? How does lighting level and type of lighting affect the results? What is acceptable or unacceptable? These are but a few questions which can be relevant to proper performance of visual examination.

This module describes visual examination as an independent inspection activity. It describes features of those examinations performed altogether visually. The concepts presented will also apply, at least in part, to the visual examination portions of all other types of examinations which employ visual techniques.

Initial Activity

Prior to studying this module, the student/trainee is encouraged to perform the activity described below to gain an initial appreciation of visual examination.

This activity requires that you examine your hand which is not used for writing. Complete the activity by accomplishing each of the following instructions in the order they are presented.

- Visually examine, for 4 or 5 seconds, your hand that is not used for writing.
- Place the examined hand out of view, such as under your desk or table, and do not look at it again until instructed to do so.

- Very candidly, complete the following statements and answer the corresponding questions.

(1) May hand is normal abnormal
What are the abnormalities, if any?

(2) My hand has four fingers and one thumb. true false.
Where these actually counted? yes no.

(3) All of the four fingernails are present not present.
Where these actually counted ? yes no.

(4) How many of the fingernails are split? ________.
Was this characteristic looked for? yes no.

(5) The hand is clean not clean.
Was cleanliness actually looked for? yes no?

(6) There are _____ (number) of rings on the fingers of the hand.
Was the number of rings actually counted? yes no?

(7) Each finger, if complete, has three phalanxes.
Which fingers have hair in the area of the middle phalanx.
index finger
middle finger
ring
little finger
none
Was this characteristic actually looked for?
yes no?

- Count the number of yes and no answers and calculate your inspection efficiency.

____ yes answers

____ no answers

$$\text{efficiency \%} = \frac{\text{number of yes answers}}{\text{total number of yes and no answers}} \times 100\%$$

- Reexamine your hand and check your entry for normality of the hand. Look for scars; unhealed cuts, burns and abrasions; warts; moles; missing nails, digits or other portions; and split nails. If any of these are present, your hand could be considered abnormal. Was your initial answer correct?
- Reexamine your hand for cleanliness. Is there any evidence of dirt, ink, pencil marks, or stains? Are the nails clean? Was your initial answer correct?

MODULE PREREQUISITES

None.

OBJECTIVES

Upon completion of this module, the student/trainee shall be able to do the following:

1. Define visually discernable attribute and name at least seven characteristics of product which are visually discernable.
2. Given any of ten characteristics which are visually discernable, describe the make-up of the characteristics as applied to visual examination.

3. Name six techniques for performing visual examination and describe each.
4. Name two types of physical acceptance standards and differentiate the use of each.
5. Give two reasons why physical acceptance standards are beneficial to visual examination.
6. Name three personnel skills and physical qualities and relate them with their effect on visual examination.
7. State four advantages and disadvantages of visual examination.
8. Name three types of operations where visual examination is typically employed by any company and give the purpose of each application.
9. State the application of translucent visual examination and briefly describe how this examination is performed.

NOTES TO INSTRUCTOR / STUDENT

It is recommended that activities be established for student/trainee visual examination of product. Guidelines for such activities are given by the module.

Advance preparation will be necessary to obtain product and associated drawings or written acceptance standards. Such products could be scrap components obtained from nearby industries. Products produced by work shops within your institute may be obtainable. Also, relatively inexpensive products could be purchased e.g., fasteners, fittings, spacers, washers, etc. Details of the visual examination exercises will be discussed later in this module.

SUBJECT MATTER

ELEMENTS OF VISUAL EXAMINATION

What comprises visual examination? What are its basic elements? While there are many factors involved to varying degrees dependent on specific applications, the elements of any visual examinations involve the questions of what, how, why and by whom. What can be visually examined? How should visual examination be performed? Why is it performed? By whom should it be performed? Answers to these questions are expressed within four basic elements of visual examination:

- visually discernable attributes
- visual examination techniques
- acceptance standards
- personnel skills and physical qualities.

Visually Discernable Attributes

Visually discernable attributes are product characteristics capable of being examined visually for purposes of comparison to a standard. A product characteristic is visually discernable if it can be seen and judged to a standard either quantitatively or qualitatively. Therefore, the acceptance standard determines whether a given product characteristic is visually discernable. For example, sorting pipe lengths by 4, 6, 8, 10 and 12 feet increments can be accomplished visually, but judging if a given pipe is within its 1/16 inch tolerance for length cannot be done solely by visual examination.

Product characteristics which are visually discernable typically fall into ten categories. These are identity, certification, count, shape, orientation, contour, surface condition, cleanliness and preservation.

- identity - This characteristic refers to both the kind of item and the identification marking on the item. First, is the item the kind of item required? For example, if the item is supposed to be a 300 gallon per minute centrifugal pump, is it? The visual examiner sees that it is a pump, its shape is of the centrifugal design, and its nameplate identifies its capacity as 300 gallons per minute. Secondly, is the item properly identified? Using the same example pump, the visual examiner determines from the drawing or specification that a nameplate is required which identifies name, classification, flow capacity, pressure rating, and serial number. Visual examination of the nameplate data determines compliance with these requirements. There are many case histories of problems with identification marking. Most pertain to legibility and omissions. There are also case histories of problems with incorrect kind of items. Examples include 3 position switches where 4 position switches were required, fasteners with course threads were required, incorrect size of fittings, and incorrect grade of materials.

- certification - This characteristic refers to certification paperwork from one company to another and to completion of paperwork within a company. In the first meaning, certifications are provided for delivered items in the form of Certified Material Test Reports for materials and Data Reports for components. The visual examination always includes checking for presence of these documents and may include review of their content. In some cases, the visual examiner refers the documents to engineers or specialists for review of content. The second meaning of certification pertains to checking for signoffs of prior operations at the time of visual examination. The visual examiner determines that paperwork accompanying the product has been signed for prior operations.

- count - The physical count of an item is frequently important. The count may be associated with a whole unit or with individual features of the unit. Case histories abound on problems which could have been avoided by proper count. Four terminal relays have been received when five terminals are required. Work has been drastically delayed when the supposed number on hand was found to be a lesser number. Examples of count are:
  (1) number of units received or issued.
  (2) number of bolt holes.
  (3) number of nozzles.
  (4) number of support mounts.
  (5) number of terminal boxes.
  (6) number of terminals within a box or on a relay.
  (7) number of strands within a wire or cable.

- shape - This characterisitc refers to the overall space envelope occupied by an item. It is the outline of the item from a number of viewpoints. Again, case histories abound on problems with shape. Examples include incorrect or omission of weld joint preparations and square head bolts vice hex head bolts.
- orientation - Experienced inspectors have a saying, "Does it look like the drawing?" They are mentally picturing the shape and orientation elements and comparing them with the drawing. Orientation refers to agreement between the product's physical configuration and that required by the drawing. One of the most difficult orientation problems to detect is the "mirror image" where the item is 180° out of orientation. At first appearance, it "looks like the drawing" but closer examination reveals that left-hand features

are on the right side and vice versa. Recently, a reactor pressure vessel was installed only to discover that all nozzles were 180° misoriented. While function was unaffected, major rerouting of piping was necessary at a large cost. Examples of features particularly susceptible to misorientation are:

(1) bridge wall arrows which indicate direction of flow
(2) nozzles
(3) bored and drilled holes
(4) support mounts
(5) terminal boxes
(6) vents and drains
(7) test connections

- contour - This characteristic refers to the shape of the surface of a feature whereas the characteristic of shape refers to the overall shape of the item. As applied to visual examination, it calls for a qualitative judgement on surface elements such as flatness, roundness, straightness, waviness and profile. Probable the most common application involves profile, i.e., does the surface outline look like the drawing? It is this application which quickly distinguishes a dromedary from a bactrian camel. A specific feature almost always examined solely by visual examination is the "breaking of corners". Designs frequently require a bevel or radius relief on inside and outside corners to reduce the stress concentration in service. The presence of such relief is determined by visual examination.
- surface condition - This characteristic refers to surface roughness and flaws. Roughness is defined as space surface irregularities. Flaws include cracks, pits, gas blow holes, nicks, scratches, gouges, seams,

and burrs. There are many case histories of items received with unacceptable surface conditions.

- color - Oftentimes, color is not relevant to visual examination of nuclear products. When it is, it typically pertains to the desired color or a product rather than the ability to distinguish a defect by its color. For example, electrical wire and cable are visually examined for insulation or covering of proper color. Raw materials are frequently identified by marking with a color-code scheme. On the other hand, a material flaw may be accompanied by a discoloration. Normally, visual examination is concerned with the presence of the flaw and not associated color characteristics.
- cleanliness - This characteristic refers to an absence of foreign materials on inside and outside surfaces of an item. Visual examination for cleanliness normally involves looking for dirt, lint, oil, grease, scale, loose oxides, and any other object which should not be present. Again, case histories of insufficient cleanliness abound. The most dramatic ones involve objects such as pieces of grinding wheels or cleaning cloths found in components upon system flush after the components have been installed.
- preservation - As used here, preservation includes any special treatment of a surface which preserves the surface in storage or in use. With this definition, it includes plating, hard surfacing, coating, and painting. Visual examination determines the presence of preservation and the surface condition and cleanliness of the preservation surface. It also includes presence and count of dessicants which are sometimes required for items in transit or storage. Desiccants control humidity by moisture absorption.

Visual Examination Techniques

The best technique for performing visual examination varies somewhat from one application to another. Visual examinations of individual parts may look for only one or two characteristics while examination of assembled components or installed systems may look for all visually discernable attributes. Nonetheless, there are six techniques common to all visual examinations. These techniques are described as follows:

- establish the attributes to be examined - Prior to commencing visual examination of product, the specific product attributes to be examined are determined. Preplanned inspection check lists may list these or the inspector may be expected to determine such attributes from the drawing or written standard governing the product. Exercising this technique firmly establishes what attributes are viewed and tends to avoid omission of attributes by the examiner.
- establish a routine sequence of examination - Once the attributes to be examined are known, a pattern for their examination helps to ensure that each is examined. The exact sequence used is a matter of personal preference. However, use of the same sequence each time provides for fastest examination and least probability of omission of examinations. Using a routine sequence is particularly important for examination of assemblies and installations where many or all visually discernable attributes are examined. In such cases, the author recommends the following sequence:
  (1) identity
  (2) certification
  (3) count

(4) shape
(5) orientation
(6) cleanliness
(7) contour
(8) surface condition
(9) preservation

- ensure proper lighting - Light directed onto the product, reflected light from the product, and background light all affect ability to perform visual examination. However, the "proper" lighting is open to diverse opinions. For accurate conclusions on lighting effects, work-place studies using real product are the best solution. Nonetheless, the following generalities typically apply.
  (1) intensity of 50 to 150 foot candles is normally sufficient.
  (2) direct lighting tends to cause more eye fatigue than indirect lighting.
  (3) light reflected from the surface of the product causes eye fatigue and, dependent on the surface, can mask the characteristics looked for. Placing direct lighting sources slightly behind the examiner will tend to cause reflected light to bounce away from the examiner and reduce fatigue.
  (4) insufficient background light causes eye fatigue; however, extraneous light can interfere with the examination.
  (5) certain types of light "enhance" the product characteristic. For example, the ghoulish green light of mercury units tend to give a three dimensional appearance to flaws on highly polished surfaces.

(6) the type of light influences the color appearance of the product.

- use of aids as necessary - Visual aids refer to any device which increases capability of performing visual inspection. Aid typically include portable light sources, mirrors, magnifying lenses, physical acceptance standards, and measuring devices. These are described as follows:

  (1) portable lights - These include flashlights as well as portable fluorescent or incandescent lamps connected to electrical power outlets. The latter are preferred because their intensity is more stable.

  (2) mirrors - A wide variety of mirrors, handles, extentions, flexible joints, and holders are available. Whenever the eye cannot be placed within 12 to 20 inches of the surface, mirrors should be used. Also, mirrors should be used if the surface cannot be viewed from 60° either side of perpendicular to the surface. Self illuminated mirrors, such as borescopes, are used for examining inside surfaces of tubing and other inaccessable areas.

  (3) magnifying lenses - Mangification is used primarily to examine "suspect" conditions, i.e., those characteristics which appear to border on the acceptance standard limit. However, acceptance standards sometimes require a specific magnification, e.g., no cracks when viewed at 5X.

  (4) physical acceptance standards - Product specimens are sometimes used as a physical acceptance standard. When they are used, the examiner must use the same techniques for viewing the

acceptance standard as used for viewing the product. This means using the same lighting, mirrors, and magnification, as applicable.

(5) measuring devices - Visual examination is frequently used for examining size or form features whose dimensions need not be accurately measured. In such cases, devices are employed to aid in the visual measurement. Such devices include templates, overlays, fixed contour gages, fixed radius gages, straight edges, and fixed length standards. Placing the device against the product feature permits visual comparison for acceptance purposes.

- look for the oddity - Once the examiner has become thoroughly familiar with exactly what is acceptable, time and energies are wasted if the examiner ponders on conditions equal to or better than the acceptance standard. The story is told of a pioneer trapper who came to the clearing with his cabin and surveyed the area. The story tells of all the detail present in twigs, leaves, tree trunks, grass, stones, flowers, moss, and so on. Yet, the story states the trapper didn't see a thing! But, had there been one detail which had been disturbed, the trapper would have detected it instantly, for his life depended on such vigilance. The visual examiner must acquire the habit of instantly seeing the oddity, the unusual, or that which is not as it should be.
- examine for all required attributes - The visual examination is incomplete until all required discernable attributes are examined. When defects are found, a tendency exists to report those defects and terminate the examination. Inspection must guard against premature termination of the examina-

tion. Correction of reported defects is normally verified by reexamination of the correction only. Any attributes not examined initially remain unexamined.

Acceptance Standards

Acceptance standards for visual examination are stated by drawings or specifications or both. When drawings are prepared to include all acceptance standards required by governing specifications, only the drawing is used to plan for and perform visual examination. However, when the drawing references governing specifications for acceptance standards, both documents are used. When both documents are used, the QA/QC department normally prepares visual examination instructions which delineate the acceptance standards of the specification. In this manner, the visual examiner can perform the examination using the drawing and the prepared instructions without researching a specification to extract those requirements pertinent to visual examination.

The acceptance standards given by the product drawing and specification dictate the attributes to be examined. For example, if acceptance standards are given for surface flaws but not for surface roughness, the examination looks for flaws only. The QA/QC department of many companies prepare inspection instructions which delineate the specific attributes to be examined by the visual examiner. Other companies require the visual examiner to determine from the drawing (and possibly the specification) those attributes to be examined. The former practice has a primary advantage over the latter practice in that consistency among examiners is better ensured by ruling out individual interpretations.

In lieu of providing written acceptance standards, physical acceptance standards are frequently employed for visual examination. There are basically two types of physical standards: limit standard and range standards.

The limit standard represents the minimum acceptable condition of the product. Therefore, any product that appears to be worse than the standard is unacceptable.

The range standard is comprized of a range of appearances from clearly acceptable to clearly defective. From this standard, all concerned parties (engineering, quality control, customer representatives) agree on either the exact single limit standard or several limit standards which establish "grades" of defects.

Physical acceptance standards provide for more accurate visual examinations for two reasons:

- more concise meaning is conveyed to the visual examiner than by written standards.
- direct comparison of the product with the acceptance standard is provided.

Personnel Skills and Physical Qualities

Mostly, visual examinations employ the senses and mental intelligence. Manual dexterity is not particularly important. The qualities which are demanded of the visual examiner are visual acuity and color discrimination, knowledge of product processing, and conscientiousness. Each of these qualities are described as follows:

- visual acuity and color discrimination - Near distance vision is important to all visual examinations. Candidates for visual examiners are required to pass a near distance visual acuity test such as demonstrating the ability to read Jaeger #1 letters at a distance of 12 to 18 inches. The examiner is repeated annually since visual acuity can change with time. If corrective lenses are required to pass this test at any time, corrective lenses must be used whenever performing visual examinations. Color discrimination is normally not required for visual examination. When color is an attribute being examined, the candidate must pass a color discrimination test. This test is not repeated because color perception does not change with time.

- knowledge of product processing - Visual examiners are better equipped to detect defects if they understand causes of possible defects. Knowledge of prior processing and the characteristic defects of such processing helps the visual examiner to know what is being looked for. Similarly, knowledge of subsequent processing and the effect of defects on such processing helps to establish the importance of the acceptance standards. For example, seeing a burr prohibit later assembly gives a better appreciation for the limits on the burrs.
- conscientiousness - Repetitive visual examination of items creates monotony. Visual examination of assemblies and installations may be tiresome because many surfaces and attributes must be viewed. Everyone has probably heard versions of the three eyewitnesses to an automobile accident who upon testifying appeared to be describing three different accidents. The visual examiner must know what to look for and diligently look. The examination must be as critical of the last piece as the first. Each attribute must be examined no matter how many exist. Therefore, the visual examiner must be conscientious. Such conscientiousness must recognize when fatigue or distractions are interferring and act to eliminate them. With respect to eye fatigue, short rest break are normally sufficient. The eye has great recuperative ability and a few minutes rest normally restores the necessary alertness.

APPLICATION

Advantages and Disadvantages of Visual Examination

Visual examinations are employed for determining acceptance of any attribute that is visually discernable in terms of the acceptance standard. This is because of the overwhelming advantages of visual inspection as compared to other examination methods. These advantages are as follows:

- Typically faster and cheaper
- Employs little or no test equipment
- Typically requires little environmental controls
- Adaptable to any job site location
- Capable of examining many different attributes within a single operation.

As previously emphasized, visual examination is limited to applications where compliance with acceptance standards is visually discernable. Therefore, the limitation of sight is the largest disadvantage of visual examination. When visual examination is employed, its other disadvantages are compensated for by training of personnel, using visual aids, and, if necessary, reexamining product by a second examiner. The other disadvantages are as follows.

- Susceptible to variance in results due to human factors
- Susceptible to variance in results due to lighting
- Difficulty of measuring size and form

Application to Product Life Cycles

Visual examinations are employed at each place of the product's life cycle as illustrated in Figure 26-1-1.

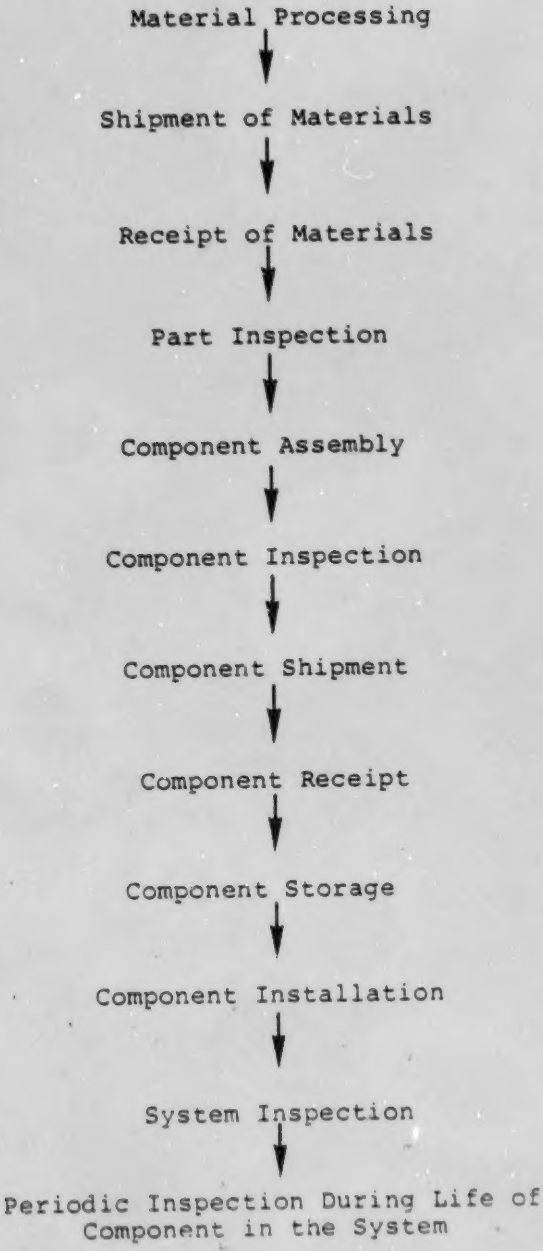

Material Processing
Shipment of Materials
Receipt of Materials
Part Inspection
Component Assembly
Component Inspection
Component Shipment
Component Receipt
Component Storage
Component Installation
System Inspection
Periodic Inspection During Life of Component in the System

Figure 26-1-1 Application of Visual Examination to Product Life Cycle

Within a given company, the product life cycle illustrated in Figure 26-6-1 typically occurs within three types of operations.

Visual examination is normally applied to these three operations. These operations and the purposes of visual examination for each are:

- receipt of items - Visual examination determines that the items received are those ordered and are acceptable.
- final part of component inspection - Visual examination determines that visually discernable attributes of the part or component in its final state are acceptable. This examination is normally performed immediately prior to release for shipment.
- assembly or installation - Visual examination is typically applied at the outset of assembly or installation and either periodically or continuously throughout the assembly or installation. It confirms use of correct items, use of work practices which do not degrade the quality of the items, and acceptability of the completed assembly or installation.

Translucent Visual Examination

A special application of visual examination is termed translucent visual examination. This type of examination employs the properties of directional lighting to examine translucent materials. Collimated light is directed through the material such that the light is evenly diffused through the material. Flaws in the material or variances in material thickness are visible as areas of different light density when viewed from the side opposite the light source. The intensity of the collimated light source determines the sensitivity of the examination. Background lighting must be less than the applied light on the surface being viewed and must be arranged to eliminate surface glares and reflection.

EXERCISES

It is recommended that products be obtained for visual examination by students/trainees. The products could be scrap components obtained from nearby industries or relatively inexpensive purchased components such as fittings, threaded fasteners, spacers, washers, etc. Either drawings or written acceptance standards should be available for each type of product. Guidelines for two activities in connection with each type or product are given below.

Exercise #1, Preparation of Visual Examination Procedure

1. Given: A product and its corresponding drawing and/or written acceptance standard.

2. Task: Prepare a procedure which gives instructions for visually examining the product. Include the following in the procedure as appropriate:
   a. attributes to be examined
   b. visual aids to be used
   c. lighting to be used
   d. sequence of examination
   e. record to be completed

Exercise #2, Performing Visual Examination

1. Given: A product, its corresponding drawing or written acceptance standard, and visual examination procedure.

2. Task: Perform the visual inspection in accordance with the procedure. Prepare a report which describes the following:
    a. each defective product noted and reason for considering it defective
    b. adequacy of procedure; for each inadequacy, state specific improvement recommended.

MATERIALS

1. Product suitable for visual examination
2. Drawings and written acceptance standards for such product
3. Portable lighting
4. Assortment of mirrors, magnifying lenses, rules, radius gages, fixed length standards and templates as required for the visual inspection.

PROCEDURES

In performing the exercises suggested for this module a written procedure for a visual examination is requested. Ensure that the written procedure identifies:

1. What can be visually examined?
2. How should visual examination be performed?

3. Why is it performed?
4. By whom should it be performed?

DATA TABLE

None.

REFERENCE MATERIALS

J.M. Juran, Quality Control Handbook, McGraw-Hill
Kennedy and Andrews, Inspection and Gaging, Industrial Press
American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section V, ASME, New York, N.Y.

TEST

1. Briefly explain what is meant by each of the following product characteristics which are visibly discernable:
   a. identity
   b. certification
   c. shape
   d. contour
   e. surface condition.

2. Briefly explain the importance of proper lighting in performing a visual examination of a product.

3. List five visual aids which may be used to increase the capability of performing a visual inspection.

4. Acceptance standards for visual examination are stated by drawings or specifications or both. Explain two types of physical acceptance standards and differentiate the use of each.

5. Briefly explain three personnel skills and physical qualities and relate them to their effect on visual examination.

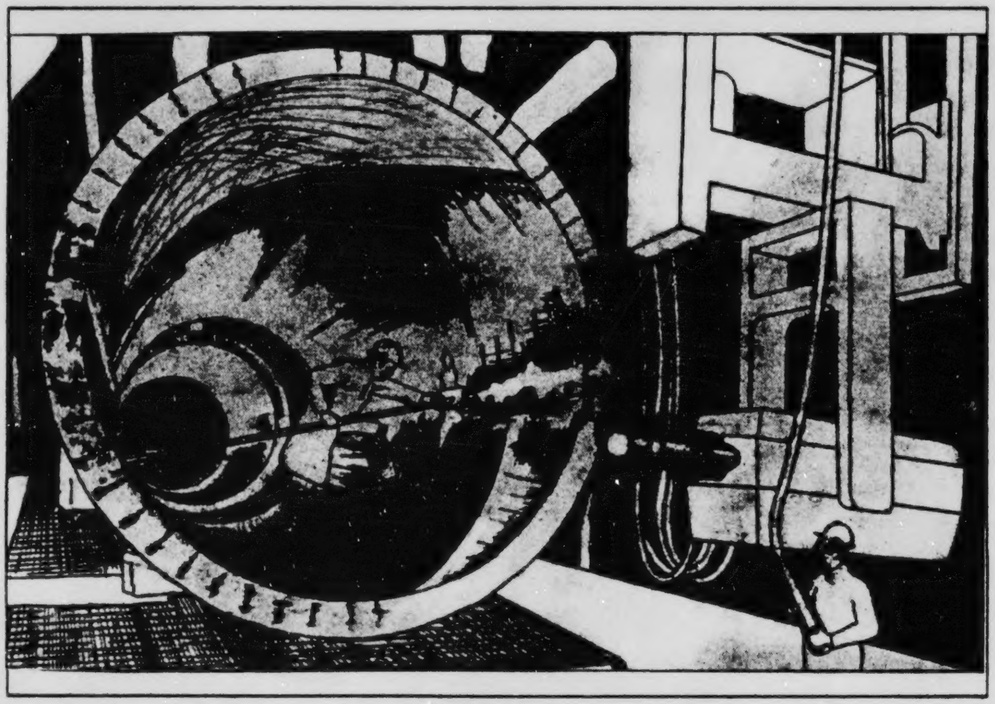
6. List three advantages and three disadvantages of the visual examination.

7. Explain the purpose of the translucent visual examination.

NUCLEAR TECHNOLOGY

MODULE 26 - 2

LEAK TESTS



COURSE 26: NONDESTRUCTIVE EXAMINATION (NDE)

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
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COURSE 26 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES I

MODULE 26-1	Visual Tests
MODULE 26-2	Leak Tests
MODULE 26-3	Hydrostatic Tests
MODULE 26-4	Liquid Penetrant
MODULE 26-5	Fundamentals of Radiography
MODULE 26-6	Radiograph Inspection
MODULE 26-7	Radiographic Specifications and Code Requirements

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INTRODUCTION

Leak testing is a nondestructive test for determining the integrity of boundaries in pressurized and evacuating systems. While it can be used to test any fluid system, it is primarily used for testing systems which must either contain pressurized gas or hold a vacuum. It is also widely used for testing sealed components for adequacy of their seal.

With respect to nuclear power plants, certain leak test methods are used predominantly. This module describes these test methods, the testing techniques and the associated quality assurance requirements.

The Nuclear QA/QC Technician may have one or more of the following responsibilities with regard to leak testing:

- qualify as a leak tester and perform leak tests
- monitor the performance of leak tests by others
- review leak test results for compliance with written acceptance criteria
- assist in the planning for leak testing including assisting in the review of leak test procedures.

MODULE PREREQUISITES

Completion of High School level classical physics or general science course.

OBJECTIVES

Upon completion of this module, the student/trainee can do the following:

1. Briefly describe the historical development of leak testing.
2. Define the terms leak, leakage, leak rate, minimum detectable leak and minimum detectable leak rate.
3. Describe why the terms zero leakage and leak-free are inappropriate terms for leak testing.
4. Name three fundamental conditions which promote fluid flow across system boundaries and briefly describe how each condition permits leak testing.
5. Relate the relative sensitivities of the following leak test methods: unaided senses, bubble test, halogen diode detector, helium mass spectrometer and pressure decay leak test.
6. Describe the following leak test methods, include description of test equipment, calibration standards, and test techniques: bubble test, pressure decay test, halogen diode detector test, helium mass spectormeter-probe method, and helium mass spectrometer-hood method.
7. Briefly describe the contributions made by the quality assurance provisions of procedure, personnel qualification, and records in terms of quality of leak testing practices.
8. Demonstrate the ability to perform a leak test.

SUBJECT MATTER

Historical Development

For as long as vessels have been used to hold fluids, leak testing has been employed. Perhaps leak tests can be labeled as the oldest branch of nondestructive examination. Advances in leak testing have been linked with progress in the technology of containment, transport and use of fluids and exclusion of fluids from a given vessel. Despite its practical importance, leak testing has remained until recently largely unrecognized as an independent technical discipline.

Historically, leak detection was initially used for liquid systems, i.e., first water and later for other liquids. The development of closed pressurized distribution systems increased the importance of leak detection. Early forms of leak detection consisted of either visual examination or listening for the sounds of air rushing out of (or into) the system. Later, leaks were detected by observing the change in pressure by using a manometer or pressure gage. In 1885, a U.S. Patent was issued for a submergence test method and in 1934 a patent was issued for a bubble test solution. The earliest use of either of these test methods is not known.

The development of steam power in the late 18th century and continuing through the 19th century and the attendent progress in pressure vessel technology helped to stimulate leak testing technology. Within the 20th centruy, the rise in industrial production and use of hazardous fluids has hastened the development of leak detecting methods which have great sensitivity. The widespread use of closed refrigerant systems has also created a market for simple and reliable detections which are sensitive to halide leaks. Ultrasensitive leak testing methods were not required until the advent of modern vacuum technology which began with the introduction of the rotary air-sealed pump in the late 19th century.

As leak testing has advanced, it has become clear that a "leak free" or "zero leakage" containment is merely a concept. All containment systems leak; therefore, the only rational requirement that can be imposed is that such a system leak at a rate no greater than some maximum allowable rate, as long as it is within the sensitivity of a measuring system.

Terminology

Leak testing has concepts represented by the terms: leak, leakage, leak rate, minimum detectable leak, minimum detectable leak rate and leak test. These terms are defined as follows:

- leak refers to the discontinuity or passage through which a fluid flows or permeates.
- leakage refers to the fluid that has escaped through the leak.
- leak rate is the rate of fluid flow per unit time under given conditions and is normally expressed in units of mass per unit time but may be expressed in units of volume per unit time.
- minimum detectable leak is the smallest leak that can be accurately observed by the test method used.
- minimum detectable leak rate is the smallest amount of leak that can be determined using a specific test method.
- leak test is the method for determining the rate at which a liquid or gas will penetrate from inside a "tight" component or assembly to the outside, or vice versa.

Units of Measurement of Leakage

Several variables affect the leak rate from a given leak. Such variables include mass of the fluid, type of flow and pressure differential. Mass units are typically used for expressing leak rate in order to have a unit which can easily be correlated with all possible variables. In order to express leak rates in mass units, the product of pressure and volume per unit time is chosen because at a constant temperature the product of pressure and volume is proportional to the mass of the leakage. Thus, the unit of leakage measurement most commonly used is standard atmosphere-cubic centimeter per second, i.e., atm-cm^3/sec.

The standard atmosphere is defined as a pressure of 1,013,250 dynes per square centimeter. It is equal to the pressure exerted by a 760 millimeter (mm) column of mercury at standard gravity. The torr is a unit equal to 1/760 atm or 1 mm of mercury. The torr pressure and liter volume unit is used by some to express leak rate, i.e., torr-liter/second.

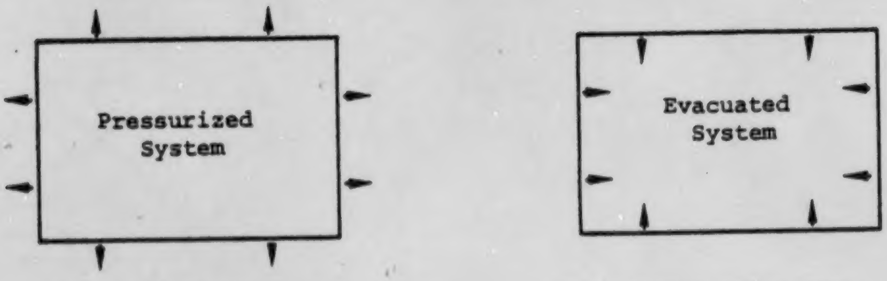
Conversion factors associated with these units are given in the Appendix to this module.

Fundamental Test Concepts

If leaks are to be detected, the test method must establish conditions which promote fluid flow through the leak. In addition, the test method must be sensitive to at least one characteristic of the leakage.

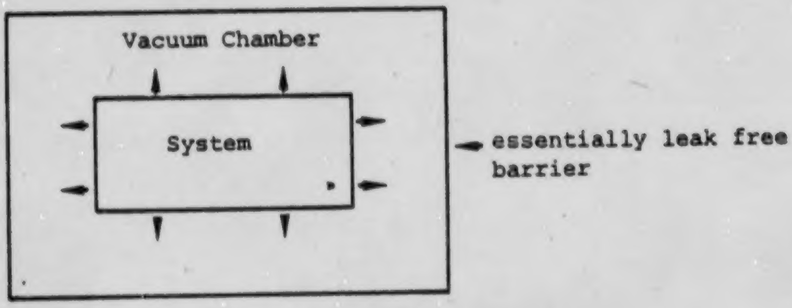
Conditions established for promoting fluid flow through leaks are either system at pressure or system at vacuum or a combination of these two. Figure 26-2-1 illustrates these concepts.

In the system at pressure test, the system is pressurized at a pressure greater than the pressure of its surroundings. Leakage occurs from the system to the surroundings. In the system at vacuum test, the system is evacuated to a pressure lower than that of its surroundings. Leakage occurs from the surroundings into the system. In the pressure-vacuum combination test, the system is at some pressure (may be


Pressurized
System
Evacuated
System

(a) System at Pressure

(b) System at Vacuum


Vacuum Chamber
System
essentially leak free
barrier

(c) Pressure - Vacuum Combination

Figure 26-2-1 Leak Test Concepts

atmospheric) and it is surrounded by an artificially created vacuum. The vacuum chamber must have a considerably less leak rate than that of the system. The leakage to be detected flows from the system into the vacuum chamber.

The fluid used as the test medium must be detectable by the test method. For example, if unaided sense of smell is to be used, ammonia would be a good test medium. The specific test media typically used are described later in conjunction with specific test methods.

Reasons for Leak Testing

Leak testing has three basic capabilities: detecting the presence of leaks, measuring leak rates and identifying locations of leaks. As described later in this module, not all leak test methods provide all these capabilities. Some methods can only detect the presence of a leak while other methods possess two or all three capabilities.

Leak testing is specified by engineering specifications and drawings applicable to the manufacture, installation, and operation of power plant equipment. Such tests are specified for individual components and for systems where it is necessary to determine either presence of leaks or leak rate. In general, such tests are specified when it is necessary to accomplish any of the following:

- prevent loss of contents
- prevent contamination of working fluid
- detect unreliable components
- assure maintenance of a pressure differential

Categories of Leak Testing Methods

For ease in understanding leak testing, it is necessary to categorize the methods in use today. There are two broad categories: system at pressure and system at vacuum. The system at pressure category is further categorized by the type of test fluid, i.e., liquid or gas. Finally, gas systems at pressure are categorized as either direct sensing or quantity loss of test methods. Figure 26-2-2 lists the various methods available today.

The test methods used at a nuclear power plant are primarily those for systems at pressure utilizing either the direct sensing gas or liquid leak test methods. The direct sensing gas methods typically used are bubble solution, halogen gas, differential pressure and mass spectrometry.

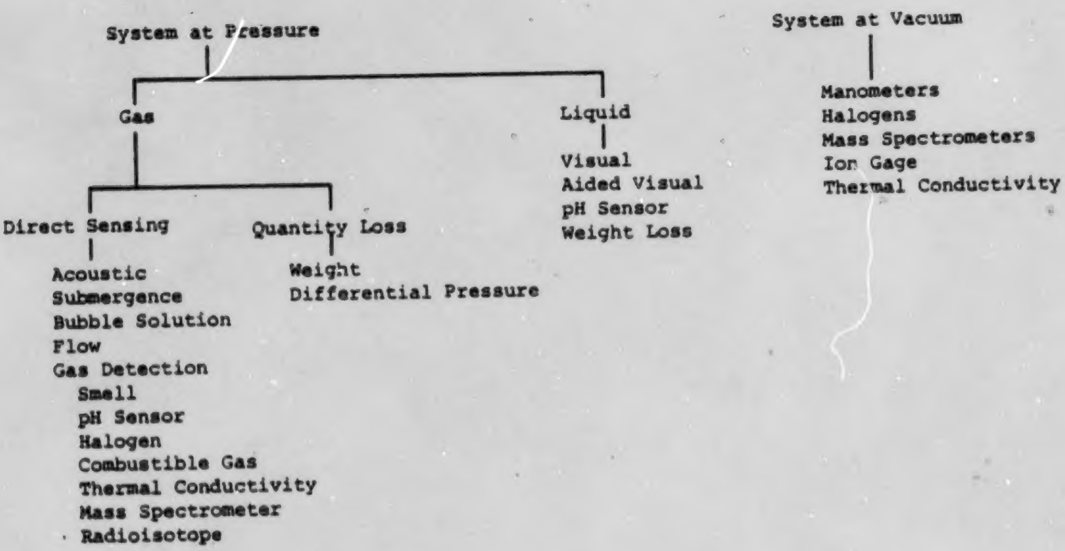

System at Pressure
Gas
Liquid
Direct Sensing
Quantity Loss
Acoustic
Submergence
Bubble Solution
Flow
Gas Detection
Smell
pH Sensor
Halogen
Combustible Gas
Thermal Conductivity
Mass Spectrometer
Radioisotope
Weight
Differential Pressure
Visual
Aided Visual
pH Sensor
Weight Loss
System at Vacuum
Manometers
Halogens
Mass Spectrometers
Ion Gage
Thermal Conductivity

Figure 26-2-2 Leak Test Methods

The liquid test methods used are usually limited to visual leak detection tests. In addition, halogen gas detector and mass spectrometer methods may be used with system at vacuum test. The remainder of the test methods are normally seen in either the manufacturer's test facility or at an independent testing laboratory for the testing of individual components.

Each test method is categorized by sensitivity as high, moderate, or low. Table 26-2-1 lists the relative sensitivities of leak test methods and Figure 26-2-3 illustrates typical sensitivities of various leak test methods.

Table 26-2-1

Relative Sensitivity of Leak Detection Methods and Equipment

Test Method	Relative Sensitivity
Unaided senses	
Eyes	↑
Ears	
Noes (usual)	Low
Aided senses	
Bubble solutions/submergence	
Penetrants	
Chemical indicators	↓
Stethoscopes	↑
Combustible gas	
Halide torch	
Mass, flow, or pressure change	
	Moderate
Thermal conductivity	
Acoustic emission	↓
Vacuum gage	
Halogen detector	↑
Ion gage	High
Radioactive isotope	
Mass spectrometer	↓

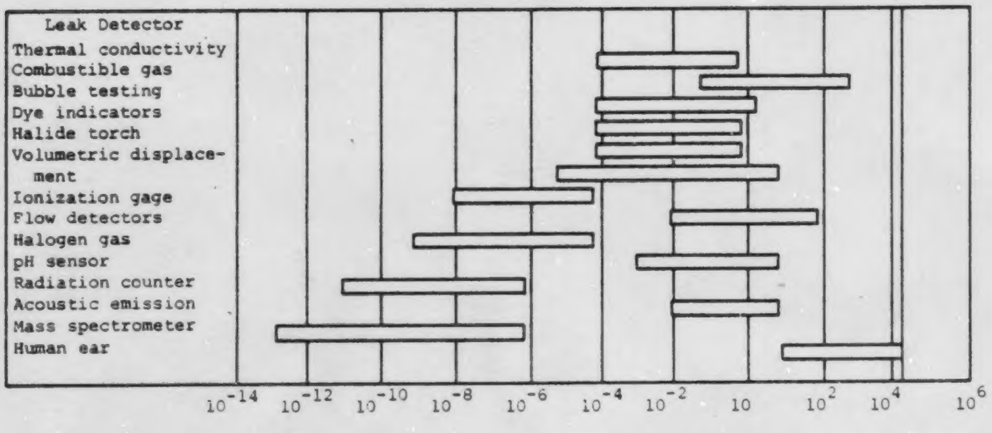


Figure 26-2-3 Sensitivity Ranges

DESCRIPTION OF LEAK TESTING METHODS

As previously indicated, the leak testing methods most commonly used with respect to nuclear power plants are bubble solution, halogen gas detectors, pressure loss, and mass spectrometers. Therefore, this module will concentrate on these test methods. Nonetheless, a brief discussion on the use of unaided senses is appropriate.

The human senses of hearing and smell should be used in conjunction with any leak test. Perhaps you have already experienced detection of natural gas leaks in furnaces, water heaters or pipe lines by smelling the leakage. While some fluids are essentially odorless, human smell can contribute to successful leak testing. Likewise, hearing is important. Many leaks are orificed such that the leakage makes an audible sound as it exits. Detection of leaks by hearing or smell indicates gross leaks because these are low sensitivity tests. In such cases, repairs are probably in order prior to proceeding with the more sensitive test methods.

Bubble Solution

Bubble solution leak testing is a relatively low sensitive test adaptable to system at pressure and pressure-vacuum combination testing. Because soap solutions were originally used for this test, it has been referred to as soap bubble testing. However, soaps and detergents contain elements which can attack the materials of items to be tested and are no longer used. Today's solutions do not contain soap or detergents, and the term soap bubble testing is obsolete.

The test is performed by applying the bubble solution such that the entire test surface is thoroughly wetted. The solution is poured on and not sprayed in order to avoid agitation which of itself may cause bubbles. Leak out of the pressurized system forms bubbles at the location of the leak. Leak rate is indeterminable with this test method. Either the atmosphere or a gaseous system's working fluid is used as the test medium for the bubble test.

Bubble testing is used where leak rate is not required to be measured. It is frequently used to determine the acceptability of welds in atmospheric and low pressure storage tanks. In this application, the pressure-vacuum combination method is used with the aid of a vacuum box. After applying the bubble solution to the weld, a vacuum box with a clear cover and a sealing material around the bottom edges is placed over the weld. A vacuum pump, connected to the vacuum box by hose and fittings, evacuates the box such that leakage is promoted from the atmospheric side of the weld into the box.

Halogen Gas Detector

The halogen gas detectors are either halogen torch detectors or halogen diode detectors. Each is capable of detecting any of the halogens: fluorine, chlorine, bromine, iodine and astatine.

The halogen (or Halide) torch detector is the oldest type of halogen detector. It has relatively low sensitivity which is essentially the same as that of the bubble test. Figure 26-2-4 illustrates the equipment associated with this test method.

The halogen torch uses a flame heated copper plate for detection. Any of the halogens or halogen compounds drawn through the intake tube by convection reacts with the copper plate. The reaction forms a copper halide which changes the color of the flame.

Halogen torches are mostly used for the detection of leaks and their location in refrigeration and air-conditioning units. It is not effective for measuring leak rate. It is

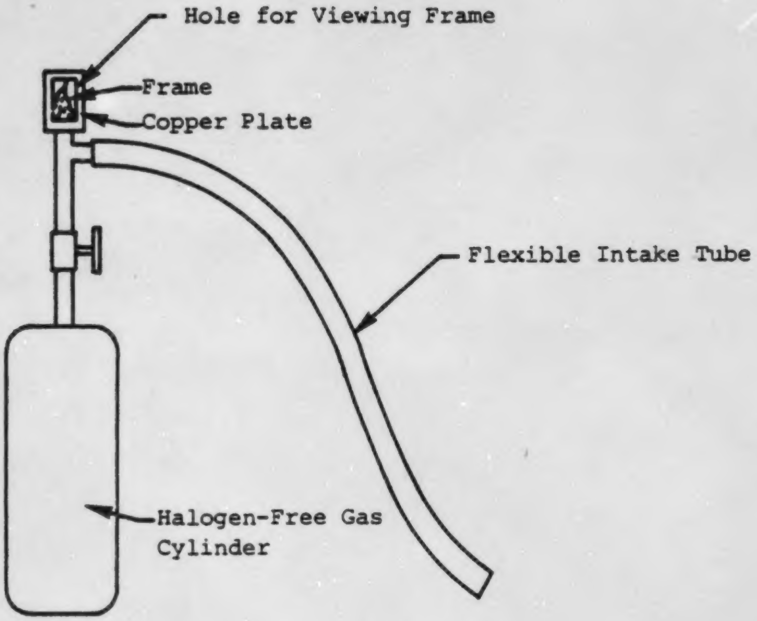


Figure 26-2-4 Halogen Torch

inexpensive, portable and simple to operate. Its disadvantages are that it cannot be used in an explosive atmosphere and, because refrigerant is heavier than air and tends to form in pockets, detection of location of leaks is difficult.

The hot-anode halogen leak detector (halogen diode) has a relatively high sensitivity. It is comprised of a probe and electronic circuitry as illustrated in Figure 26-2-5.

The detector contains a hot platinum or ceramic electrode which readily ionizes halogen atoms. This ionization produces a current between the anode and cathode of the detector. In the presence of halogen vapors, the rate of ionization is proportional to the concentration of halogen present. The electronic circuitry detects the current and displays if on the meter in units of leak rate. The hot-anode halogen detector offers the three capabilities of leak

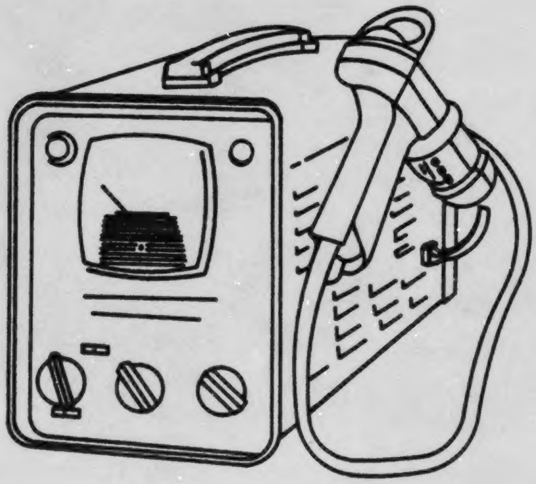


Figure 26-2-5 Hot Anode Halogen Leak Detector

detection, leak location and leak rate measurement. Its chief drawback is that halogen gases are difficult to use as tracer gases because they are generally heavy and have low diffusion rates.

Pressure Loss Leak Tests

Pressure loss (decay) leak testing is a moderately sensitive test method which includes the absolute pressure test and the differential pressure test. Absolute pressure testing monitors the pressure of a system. Pressure loss from the system without apparent cause is indicative of leakage. Differential pressure testing compares the pressure of a system with that of a reference system known to have extremely low leakage. Pressure loss from the system under test is indicated by an increased differential pressure between it and the reference system. Both tests rely on ideal gas laws.

The state of an ideal gas is expressed by the following equation:

$$PV = NRT$$

Where:

P = gas pressure
V = volume of the container of the gas
N = number of moles of gas
R = the universal gas constant
T = absolute temperature of the gas

Consider a system which is pressurized with gas to pressure B, at a temperature of T, and allowed to stand for a time period. At the end of the time period, the pressure is found to have dropped to P_2. If the temperature has not dropped and if it can be assumed that the volume has not increased, the pressure drop must be due to leakage. If the quantity of gas does not change, it follows from the earlier equation that the change in pressure must satisfy the relation:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

If $V_1 = V_2$, as assumed, then the relation becomes:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \qquad \text{(V, N, and R constant)}$$

Measurement of pressure and temperature of the system permits calculation to determine the presence of leaks. If P_2 is found to be in proportion to a drop in temperature, the system has not leaked at a discernable rate. But, if P_2 has decreased beyond proportion to any drop in temperature, leaks must exist. The amount of leakage is ΔN which is expressed by the following equation.

$$\Delta N = N_1 - N_2 = \frac{P_1}{T_1} - \frac{P_2}{T_2} \quad \frac{V}{R}$$

Leak rate is calculated by converting ΔN to mass and dividing by the time elapsed between measurements of P_1, T_1 and P_2, T_2. The mass is found by multiplying the gram-molecular weight of the gas times ΔN.

Water vapor in the test medium can seriously affect leak testing results if condensation occurs. "Dry" gas is used where possible. For example, if air is used as the test medium, the compressed air is passed through moisture separators prior to discharging the air into the system to be tested. Nonetheless, some moisture content is always present.

Condensation of water vapor is avoided by preventing the temperature of the system from reaching the dew point. If the dew point is reached, condensation occurs and pressure decay results from the change in volume. As previously indicated, volume was assumed to be constant in the pressure decay formulas used for leak testing.

Due to the concern with moisture condensation, pressure decay leak testing must include determination of dew point temperature and checks to ensure the dew point is not reached at any time during the test. Dew point temperature may be determined by use of psychrometers or hygrometers. The psychrometer consists of wet bulb and dry bulb thermometers. The wet bulb temperature is the dew point temperature. Hygrometers are instruments which give direct readout in either relative humidity (%) or dew point temperature. When relative humidity is indicated, the dew point temperature is determined by the intersection of dry bulb temperature and relative humidity with the dew point temperature as shown on a psychrometric chart. Figure 26-2-6 illustrates determination of the dew point temperature of 65°F when relative humidity and dry bulb temperature are known to be 60% and 75°F.

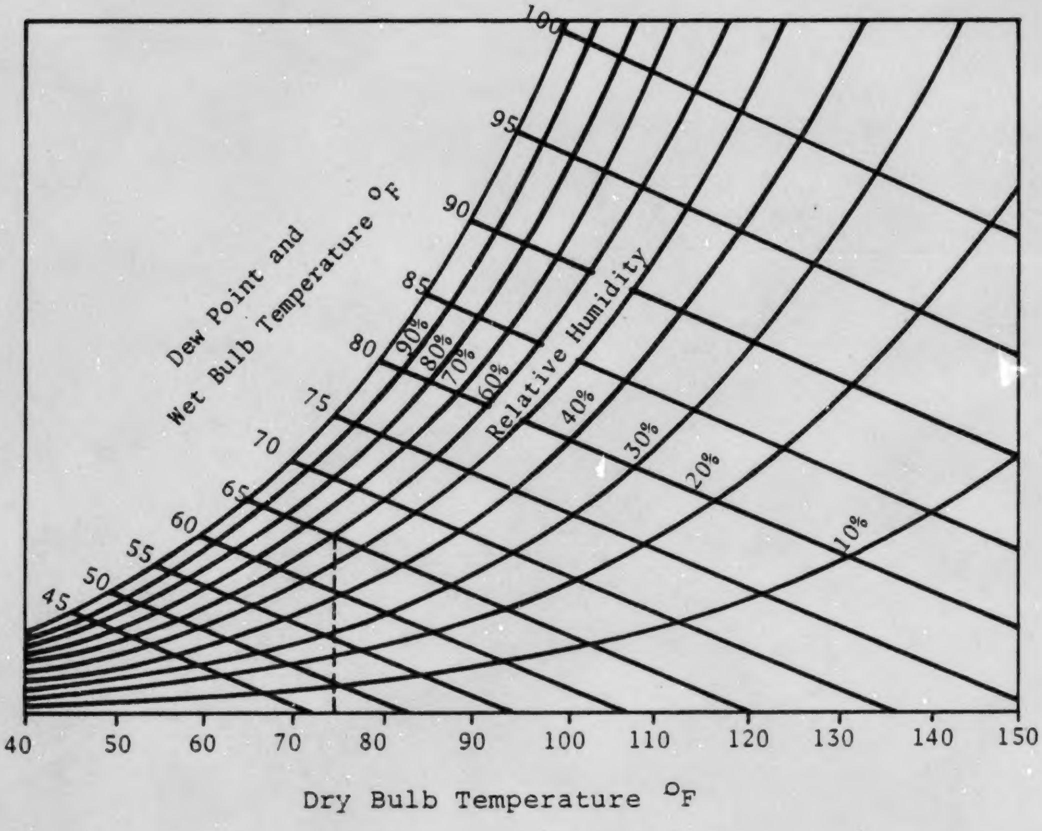


Figure 26-2-6 Psychromatic Chart

The sensitivity of pressure decay leak testing is dependent on the sensitivity and accuracy of the pressure and temperature measuring devices. Also, if very sensitive testing is required, factors are necessary to correct for volumetric expansion or contraction of the system due to pressure and temperature changes.

Since differential pressure gages can be more sensitive than absolute pressure gages, the differential pressure decay leak test method is typically more sensitive than the absolute pressure decay leak test method. The differential pressure method set-up is illustrated in Figure 26-2-7.

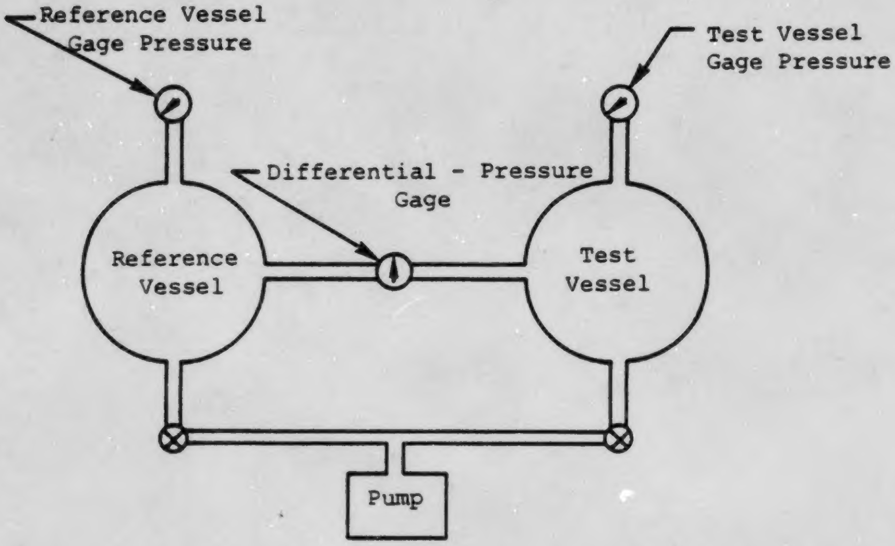

Reference Vessel Gage Pressure
Test Vessel Gage Pressure
Differential - Pressure Gage
Reference Vessel
Test Vessel
Pump

Figure 26-2-7 Simplified Diagram of Differential Pressure Leak Test

Mass Spectrometers

Mass spectrometers provide for high sensitivity leak testing. The principle component of mass spectrometers is a specially designed, evacuated tube illustrated in Figure 26-28.

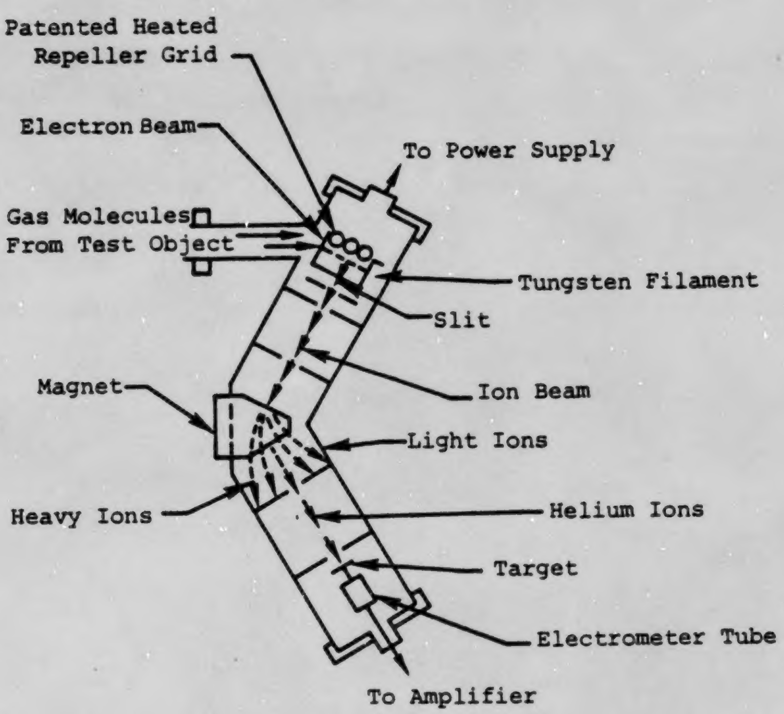

Patented Heated Repeller Grid
Electron Beam
To Power Supply
Gas Molecules From Test Object
Tungsten Filament
Slit
Magnet
Ion Beam
Light Ions
Heavy Ions
Helium Ions
Target
Electrometer Tube
To Amplifier

Figure 26-2-8 Mass Spectrometer "Veetube"
(Courtesy of Veeco Instruments, Inc.)

As leakage from the test object enter the mass spectrometer tube, the gases are ionized at the cathode. The positive ions accelerate toward a negatively charged collector or grid at the other end of the tube. In transversing the tube, the gas ions pass through a magnetic field which causes a deflection in the travel path of the ions which is proportional to their mass. Through adjustment of accelerating voltage or magnetic field strength, the tube is "tuned" such that only a given mass strikes the target. Those ions which hit the target cause a current flow which is directly proportional the concentration of gas ions. The current flow is amplified and displayed as leakage in atm-cc/sec.

Mass spectrometers in popular use for leak detection are permanently "tuned" to be sensitive to helium. Hence, these detectors are known as helium leak detectors or helium mass spectrometers.

Mass spectrometers are suitable for testing with system at pressure, system at vacuum and pressure-vacuum combinations. A tracer gas, such as helium, must be used with mass spectrometers. Procedural techniques are described later in this module.

Visual Leak Test

Visual leak tests which are associated with nuclear power plants are almost exclusively involved with hydrostatic testing. With the system filled and pressurized with water, visual inspection looks for evidence of water leakage. Further details of this test method are given in Module 26-3, Hydrostatic Testing.

LEAK TESTING TECHNIQUES

Preparation

Regardless of the specific leak test to be performed, certain preparatory steps are essentially identical. These steps include cleanliness, sealing of openings, selection of suitable instruments, and calibration of instruments.

- cleanliness - The system to be tested is examined for cleanliness of surfaces. The surfaces must be free of contaminants, such as oil, grease, and paint, which would mask a leak. If cleaning is required using liquid cleaners, the surfaces are dried prior to commencing leak testing.

- openings - Openings in the system must be sealed to permit leak testing. Plugs, covers, sealing wax, cement or other suitable material which can be readily removed may be used. If halogen detector leak testing is to be performed, the sealing materials must be free of halogens.
- instruments - Suitable instruments are selected as required by the specific test method. Pressure gages are direct reading dial-indicating types. One pressure gage must be in view of the operator who controls system pressure. Thermocouples or resistance temperature detectors are most commonly used. For pressure decay testing, either psychrometers or hygrometers are also needed.
- calibration - Any instrument used as an integral part of the test must be calibrated to a specified accuracy. Calibration is typically performed prior to initial use of the instruments and annually thereafter.

Bubble Test Techniques

Bubble tests are performed by pressurizing the system or by using a vacuum box. In either method, temperature must be above freezing or a bubble solution having a low freezing temperature must be used.

- pressurized system bubble test - Typically air is used as the test medium although nitrogen or helium may be used. The system is pressurized to the specified pressure and pressure is held for a minimum of 15 minutes to check for gross leaks and to permit permeation of fine leaks. The bubble solution is flowed onto test surfaces with care to avoid bubble formulation due to application alone. Visual examination detects presence and location of leaks. After testing, the bubble solution is cleaned from the surfaces.

- vacuum box bubble test - The bubble solution is applied to the test surface by flowing in order to minimize bubble formation. A vacuum box is connected to a vacuum pump or air ejector and placed over the test surface. The specified vacuum is achieved and held for at least 10 seconds. Visual examination through the clear cover of the vacuum box detects presence and location of leaks.

Halogen Leak Test Technique

The hot-anode halogen diode detector is typically used for halogen leak tests. These tests are typically the pressurized gas type of test. The test requires use of a tracer gas and a calibrated leak.

The system to be tested is filled and pressurized with air which contains a tracer gas of 10% by volume. To ensure a uniform mixture of tracer gas throughout the system, the system is vented as it is filled. The tracer gas is allowed to flow for a time calculated for completely purging the system. The vents are then closed and tracer gas is added until desired pressure is reached. The tracer gas is typically Refrigerant 12 but any of the gases listed in Table 26-2-2 may be used. Detection of the tracer gas external to the system indicates presence of leaks.

A calibrated leak or standard leak, is a device containing a tracer gas which leaks at a known rate. It is used to calibrate the leak detector. The probe of the halogen diode detector is slowly passed across the orifice of the calibrated leak device to determine that the instrument reading matches that of the standard leak. Passing the probe across the orifice also determines scanning rate to be used in the system test. The scanning rate must permit detection of the value of the standard leak and it is typically

Table 26-2-2

Tracer Gases for Halogen Leak Tests

Commercial Name	Chemical Designation	Chemical Symbol
Refrigerant 11	Tricholoromonofluoromethane	CCl_3F
Refrigerant 12	Dichlorodifluoromethane	CCl_2F_2
Refrigerant 21	Dichloromonofluoromethane	$CHCl_2F$
Refrigerant 22	Chlorodifluoromethane	$CHClF_2$
Refrigerant 114	Dichlorotetrafluoroethane	$C_2Cl_2F_4$
Methylene Chloride	Dichloromethane	CH_2Cl_2

on the order of ½ inch to 1 inch per second. This calibration check is performed prior to and after leak testing and at two hour intervals during prolonged tests.

After the system is pressurized with tracer gas and the halogen detector is calibrated, the external surfaces of the system are scanned with the detector probe. Scanning speed must be equal to or less than that used at calibration. The probe tip should lightly touch the test surface as it is moved. The area being scanned must be free of air drafts. If forced ventilation causes air drafts, the ventilation must be turned off temporarily or baffles must be used to prevent drafts at the test surface.

The probe draws in air from around the test surface. At the point of leaks, the tracer gas in the leak enters the probe, becomes ionized, and thus causes current flow in proportion to the leak rate. Most halogen diode detectors provide a direct readout of leak rate and some have an audible alarm to alert the operation when tracer gas is sensed.

Whenever the shell side of shell-and-tube heat exchangers are leak tested by the halogen diode detector, each tube represents an independent leak path and must be checked. The tubes are checked by placing the probe into each tube and monitoring for leakage for several seconds.

Helium Mass Spectrometer - Probe Method

Helium mass spectrometer leak testing with the probe method is very similar to leak testing with the halogen diode. As illustrated in Figure 26-2-9, the test system is pressurized with a tracer gas (helium) and the exterior surfaces are scanned with a probe to detect leakage. A calibrated leak is used to check the sensitivity of the detector.

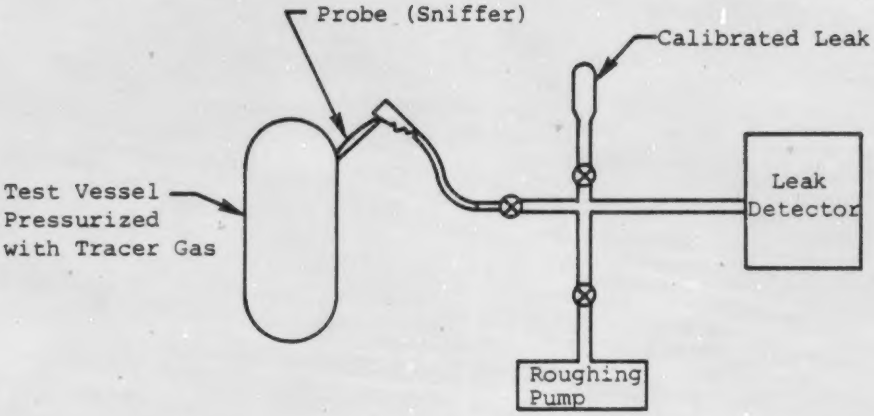


Figure 26-2-9 Connection of Probe to Detect Leaks with a Stationary Leak Detector

In helium leak testing, background readings are normally present. Small quantities of helium are in the atmosphere. Many materials absorb helium and later outgas the absorbed helium, particularly when exposed to a vacuum. Also, the helium detector has inherent electronic "noise" which contributes to background. If helium is used to test a system and then dumped in the area and testing of an adjacent system begins, the background helium will probably mask real leakage until ventilation has adequately dispersed the dumped helium. Because of these concerns, helium should never be dumped into an area where further leak testing is to be performed. Also, the sensitivity of the helium mass spectrometer is periodically checked.

The sensitivity of the helium mass spectrometer is checked by comparing the background reading with the reading obtained from probing a standard leak. Sensitivity is stated in terms of leak rate necessary to change the reading one meter division. It is calculated by the following formula:

$$S = \frac{CL}{MR - BG}$$

Where:

S = sensitivity in leak rate per meter division
CL = calibrated leak rate
MR = meter reading of calibrated leak (division)
BG = meter reading of background (division)

The specification which governs the leak test identifies the minimum required sensitivity. For example, the ASME Boiler and Pressure Vessel Code requires a minimum sensitivity of 1×10^{-9} std cm^3/sec/division.

The probe method of helium leak testing employs the following steps:

- After equipment warm-up, the sensitivity of the detector is determined. The sensitivity check is repeated at the end of the leak test and at two hour intervals during prolonged tests.
- The system is pressurized with air containing 10% helium.
- Probe scanning speed is determined by the scanning speed used in detecting the standard leak.

- The time from probing the standard leak until the standard leak is indicated on the meter is noted.
- Test surfaces are scanned at the established speed and with the tip of the probe within 1/8 inch of the surface.

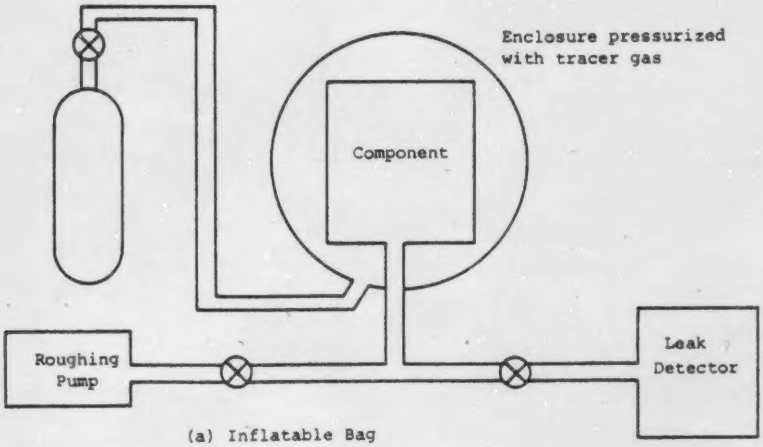
The probe method offers relatively high sensitivity. The shortest probe length possible provides best conditions. Lengths of 10 to 15 feet are typically used. When leakage is detected, a time should be allowed for purging of the probe prior to scanning other areas. This time should be greater than the reaction time noted during the calibration check.

When leak testing the shell side of shell and tube heat exchangers, probing of each tube is necessary as it is in the halogen diode detector leak test.

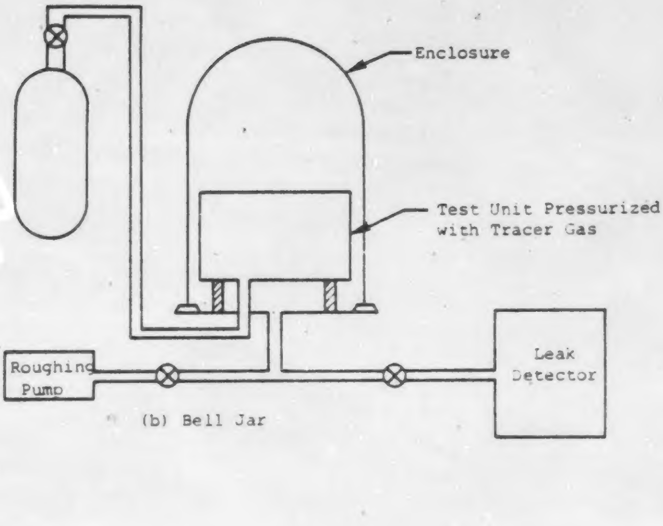
The operator of the probe often cannot see the meter on the detector unit while probing test surfaces. This disadvantage of the probe method is offset by providing an audible indication to the operator when leakage is detected. Headsets or speakers are used for this purpose.

Helium Mass Spectrometer - Hood Method

Two variations of the hood method are common. One is the encapsulation of components with a flexible barrier such as a plastic bag. The leak detector is connected to the component such that a vacuum is generated within the component. The void space between the bag and the outside surfaces of the component is pressurized with tracer gas. Leakage from the outside to the inside of the component is detected. This method is typically used for large components. The other variation is by use of the bell jar. The component is placed in a bell jar and pressurized with the tracer gas. The void between the component and the bell jar is connected to the detector such that a vacuum exists in this void. Leakage from the inside to the outside of the component is detected. This method is typically used for small components. These hood methods are illustrated in Figure 26-2-10.


Enclosure pressurized with tracer gas
Component
Roughing Pump
Leak Detector

(a) Inflatable Bag


Enclosure
Test Unit Pressurized with Tracer Gas
Roughing Pump
Leak Detector

(b) Bell Jar

Figure 26-2-10 Hood Method

The bell jar hood method is also readily adaptable to leak testing small, sealed components such as electronic devices. The technique for testing sealed components is termed "back pressuring." First, the sealed component is placed in the hood and the hood is pressurized with tracer gas. The pressure is allowed to stand for a time sufficient for the gas to enter the sealed component if leaks are present. Then the hood is evacuated. If gas entered the component, it will now escape through the same leaks and can be measured.

In each of the hood methods, the calibrated leak is connected in the detector sensing line at a distance from the detector as nearly as possible to the component's distance from the detector. Calculations are necessary to determine detector sensitivity, response time, measured leak rate, and actual leak rate.

Sensitivity and response time are determined by opening the standard leak to the detector, noting the time for response and calculating sensitivity in the same manner as the probe method. The sensitivity check is repeated if the set-up is changed. After the sensitivity test, the standard leak is isolated from the detector.

The leak test is performed with either the pressurized bag-evacuated component method or the pressurized component-evacuated hood method. The testing time must exceed the response time measured during the sensitivity check. The indicated leak rate on the meter is actually the sum of background and leakage and the value is dependent on whether pure helium or a percentage mixture is used as the tracer gas. Accordingly, immediately following the measurement of leakage, a series of calculations are made to determine actual leak rate. These calculations are performed as follows:

- Designate the original mass spectrometer background reading as BG, and the indicated leak rate from the test as MR.
- Depressurize the tracer gas volume but leave the line-up to the leak detector in tact.
- When the mass spectrometer reading stabilizes, designate the background reading as BG_2. (This provides a corrected background which includes inleakage from the hood from sources other than component leakage).
- Valve the standard leak to the detector, designate the meter reading as MR_2 and calculate a calibrated sensitivity as follows:

$$Sc = \frac{CL}{MR_2 - BG_2}$$

Where:

Sc = calibrated sensitivity
CL = Calibrated leak
MR_2 = reading with standard leak open to detector
BG_2 = background including inleakage from hood.

- Calculate measured leak rate as follows:

$$MLR = Sc\ (MR_1 - BG_1)$$

Where:

MLR = measured leak rate
Sc = calibrated sensitivity
MR_1 = meter reading from test of component
BG_1 = original background reading.

- Calculate actual leak rate by correcting for percentage of helium used as the tracer gas as follows:

$$ALR = \frac{MLR}{\%He} \times 100$$

Where:

ALR = actual leak rate of component
%He = percentage of helium used as the tracer gas
MLR = measured leak rate

EXAMPLE:

The helium mass spectrometer is used to leak test a component with the hood method using 10% helium in air as the tracer gas. Mass spectrometer backgrounds is 2 x 10^{-10} atm-cm^3/sec and the indicated leak rate is 4.7 x 10^{-8} atm-cm^3/sec. A calibrated leak of 6 x 10^{-8} atm-cm^3/sec is connected to the detector.

Given: CL = 6 x 10^{-8} atm-cm^3/sec
BG_1 = 2 x 10^{-10} atm-cm^3/sec
MR_1 = 4.7 x 10^{-8} atm-cm^3/sec
%He = 10

Solution:

- With test set up intact and tracer gas depressurized, record stabilized meter reading (BG_2). Assume reading is 5 x 10^{-10} atm-cm^3/sec.
- Open standard leak to the detector and record MR_2. (Assume MR_2 to equal 6.3 x 10^{-8} std cm^3/sec)
- calculate calibrated sensitivity:

$$Sc = \frac{CL}{MR_2 - BG_2}$$

$$= \frac{6 \times 10^{-8}}{6.3 \times 10^{-8} - 5 \times 10^{-10}} = \frac{6}{6.25} = .96$$

- calculate measured leak rate:

$$\begin{aligned} MLR &= Sc\ (MR_1 - BG_1) \\ &= .96\ (4.7 \times 10^{-8} - 2 \times 10^{-10}) \\ &= .96 \times 4.68 \times 10^{-8} \\ &\approx 4.5 \times 10^{-8}\ \text{atm-cm}^3/\text{sec} \end{aligned}$$

- calculate actual leak rate:

$$\begin{aligned} ALR &= \frac{MLR}{\%He} \times 100 \\ &= \frac{4.5 \times 10^{-8}}{10} \times 100 \\ &= 45 \times 10^{-8}\ \text{std cm}^3/\text{sec} \end{aligned}$$

Pressure Decay Testing Techniques

Techniques associated with pressure decay testing were previously described in the section on description of test methods. These techniques are summarized as follows:

- pressurize the system with air to the specified pressure (typically 60 psi).
- Record pressure and temperature as P_1 and T_1.
- Determine dew point temperature and ensure system is about dew point temperature.
- After specified time interval record pressure and temperature as P_2 and T_2.
- Calculate anticipated pressure (Pa) due to temperature change:

$$Pa = \frac{P_1\ T_2}{T_1}$$

- Compare anticipated pressure with measured pressure, P_2. If P_2 = Pa, there is no measurable leak. If P_2 < Pa, leaks are present.

COMMON ERRORS MADE IN LEAK TESTING

The most common errors made in leak testing are

- using too sensitive a test method
- using only one leak testing method
- not controlling the environment in the area of the test.

It is good practice to conduct leak tests in two or more stages beginning with the "gross leak" tests and graduating to the more sensitive methods. The reasons for this practice are obvious when it is seen that the sensitive methods cannot be used for gross leaks. Following this procedure, savings in time and money are achieved by testing initially for gross leaks.

The extent of controls of the environment in the vicinity of the leak tests is dependent on the test method used. If a search gas method is used, the atmosphere must be controlled to prevent contamination by the search gas which could possibly give an erroneous indication of leakage. If an acoustic type test is being used, background noise should be controlled. If small leaks are present, airborne particulate or contaminants may cause temporary plugging of the leak in system at vacuum tests.

QUALITY ASSURANCE PROVISIONS

To help ensure proper performance of leak testing, three quality assurance provisions apply. These are requirements for written procedure, personnel certification and records.

Written procedures are developed and implemented for each type of leak test. These procedures are typically prepared by Engineering and reviewed by Quality Assurance. The procedure provides to the qualified leak test technicians sufficient guidance to properly perform the test. The procedures typically provide instructions for accomplishing the following:

- Prerequisites to be met prior to commencing the test.
- Specific steps for conducting the test including system line-up, test equipment to be used, calibrations to be performed and test steps to be completed.
- Precautions to be observed while conducting the test.
- Acceptance criteria against which the leak rate is compared.
- Actions to take when acceptance criteria are not met.
- Reports of the leak test results.

Leak test technicians are trained and certified in accordance with a formal program established by each company that performs leak tests of safety related components and systems. Recommended Practice, SNT-TC-1A, which is published by the American Society for Nondestructive Testing, provides guidelines for establishing the personnel certification program. This document recommends training and experience as listed in Table 26-2-2 for two levels of certification. Level I testers are qualified to perform leak tests in accordance with written procedures. Level II is a higher qualification which equips the tester to interpret specifications governing leak testing.

Table 26-2-2
Recommended Training and Experience Minimum Levels
Training (Hours)

Leak Testing	Level I				Level II			
	BT	PCMT	MSLT	MSLT	BT	PCMT	HDLT	MSLT
*Completion with a passing grade of at least 2 years of engineering or science study at a university, college, or technical school	2	16	8	28	2	12	6	16
**High school graduation, diploma or its equivalent	2	24	12	40	4	16	8	24
***Grammar school graduation, or demonstrated proficiency, or additional training	2	96	48	NA	4	80	40	NA
	Work Time Experience (Months)							
All education levels are listed above	-Mo. 2 Hr	1½	1½	4	½	4	4	6

NA = Not Applicable.

BT = Bubble Test

PCMT = Pressure Change/Measurement Test

HDLT = Halogen Diode Leak Test

MSLT = Mass Spectrometer Leak Test

Asterisks refer to the Recommended Training Course Tables

Note 1: The training for Level II is in addition to that for Level I.

Note 2: Credit for exerpience may be gained simultaneously in two or more disciplines. The candidate must spend at least 25% of this work time on each discipline for which experience is being claimed.

Candidates who meet the established training and experience levels are certified upon successful completion of examination. The examination includes written and practical examination. The practical examination requires the candidate to demonstrate performance of the leak test.

Records are required of each leak test and of personnel certifications. With regard to leak test records, a report is generated for each component or system tested. The report identifies date of the test, name of the leak tester, leak test procedure number, and the test results.

SAFETY PRECAUTIONS

This section provides a brief review of standard safety precautions. The student/trainee should become familiar with precautions applicable to the laboratory or shops and obey them at all times. One of the basic rules of safety requires the proper behavior of every individual. Practical jokes and horseplay cannot be tolerated. The possible consequences are too high a price to pay for the small amount of humor derived.

Another basic rule requires good housekeeping practices. Care must be taken to keep the work area clean and free from oil. Clutter and slippery oil spots lead to accidents.

Refrigerant Safety

The following safety precautions are typical of those to be followed when using, storing or handling bottled refrigerants:

- Never drop cylinders or permit them to strike each other violently.

- The cap provided for valve protection must be kept on cylinders except when the cylinders are being used.
- Never use cylinders for any purpose other than their intended purpose. Do not use then as rollers, supports, etc.
- Do not tamper with the safety devices in the valves or cylinders.
- Make sure that the threads on regulators or other connections are the same as those on the cylinder valve outlets. Never force connections that do not fit.
- Never attempt to repair or alter cylinders or valves.
- Store cylinders in a cool dry place, in an upright position. (If the cylinders are exposed to excessive heat, a dangerous increase in pressure can occur.)
- Never allow R-12 to come in contact with a flame or red-hot metal. When exposed to excessively high temperatures, R-12 breaks down into phosegene gas, an extremely poisonous substance.

  (Note: Although R-12 is generally classified as non-toxic, it is poisonous in high concentrations such as might occur from excessive R-12 leakage in a confined or poorly ventilated space. If a person should be overcome by R-12, remove them immediately to a well-ventilated place and get medical attention at once. Watch their breathing, if the person is not breathing, begin artificial respiration.)

Industrial Gas Safety

All compressed gases are dangerous if improperly handled. Some of the more important precautions pertaining to industrial gases in addition to those listed for the refrigerant gases are:

- Constantly inspect for leaks and tighten or replace leaking fittings, hoses, etc.
- Watch all temperature and pressure indications. Small changes in temperature can result in large changes in pressure.
- Make sure hoses and fittings are always tight; do not interchange fittings or hoses with similar equipment for other gases.
- Close the valves and replace outlet caps when cylinders are not in use.

Appendix 26-2-1

Leak Rate Conversion Factors

To Convert	To	Multiply Column 1 By
STD·cm^3/s[a]	Micron liters/s	7.60×10^{-2}
	Micron ft^3/h	9.66×10^{-4}
	torr·liters/s	7.60×10^{-1}
	≅1 cm^3/day	1.16×10^{-3}
	≅1 cm^3/year	3.16×10^{-8}
Micron·liters/s	STD·cm^3/s	1.32×10^{-3}
	Micron ft^3/s	1.27×10^{-2}
	torr·liters/s	1.00×10^{-3}
torr·liter/s	STD·cm^3/s	1.32
	Micron liters/s	1.00×10^{-3}
	Micron ft^3/s	1.27×10^{-5}
Micron ft^3/s	STD·cm^3/s	1.04×10^{-5}
	Micron liters/s	7.87×10^{-3}
	torr·liters/s	7.87×10^{-6}

Example: Given: 0.1 Micron ft^3/s
Find: Number STD·cm^3/s
Solution: $0.1 \times 1.04 \times 10^{-5}$ STD·cm^3/s 1.04×10^{-6}

[a] STD·cm^3/s = atm·cm^3/s.

Appendix 26-2-2

Useful Factors in Leak Testing Work

---

1 atmosphere (atm) = 14.7 pounds per square inch absolute (psia)
= 760 millimeters of mercury (mm Hg)
= 7.6×10^{5} microns
1 micron = 1×10^{-8} meters of mercury (m Hg)
= 1×10^{-3} mm Hg
1 torr = 1/760 of a standard atmosphere
1 millitorr (mtorr) = 1×10^{-3} torr
1 microtorr (μtorr) = 1×10^{-6} torr
1 cubic foot (ft^3) = 28,320 cm^3
= 28.32 liters
= 7.48 gal
1 cubic inch ($in.^3$) = 16.4 cm^3
1 liter = 61.0 $in.^3$
= 0.0353 ft^3
= 1.0567 U.S. qt
Seconds in 1 year = 31,563,000 s/year
= 3.16×10^{7} s/year
Percentage of helium in air = 0.0004 percent
Partial pressure of helium in air at Standard Temperature Pressure (STP) = 0.00304 mm Hg
= 3.04 microns

EXERCISES

The following exercises serve to reinforce the material covered in this module.

1. Perform the Bubble Test on a test bell jar equipped with a vent valve as described in the Procedures section of this module. The Materials required for this test are also listed in the following section.

2. Perform the Helium Mass Spectrometer Test as outlined in the Procedures section of this module. The Materials required for this exercise are also listed in the following section.

3. Define the following terms:
   a. Leak
   b. Leakage
   c. Leak rate

4. Briefly describe the three sets of conditions under which leak testing may be accomplished.

5. Give three general reasons for making leak tests on systems or components.

6. Compare the following test methods as to relative sensitivity.
   a. Bubble Test
   b. Pressure Change
   c. Halogen Diode Detector
   d. Helium Mass Spectrometer

7. Indicate whether each of the following statements are true or false:

____ a. Leak tests were first performed in 1934.

____ b. Vacuum chambers used in leak testing are leak-free.

____ c. The halide torch changes color in the presence of halides.

____ d. Using the bubble test, the leak rate can be determined by timing the length of time required to form a standard bubble.

____ e. The helium mass spectrometer can be used on a system at pressure as well as a system at a vacuum.

Answer the following multiple choice questions #8 and #9.

8. A halogen diode detector will detect compounds containing
   a. Fluroine
   b. Chlorine
   c. Bromine
   d. All of the above

9. Helium mass spectrometers detect
   a. Hydrogen
   b. Helium
   c. Hafnium
   d. None of the above

10 Describe the operation of the Halogen Diode Detector.

11. Why should temperature be held above dew point temperature during pressure decay leak testing?

12. Why is differential pressure decay leak testing generally more sensitive then absolute pressure decay leak testing?

13. Describe the operation of a mass spectrometer tube.

14. Why is surface cleanliness important to leak testing?

15. Describe the pressurized system bubble test.

16. Describe the vacuum box bubble test.

17. Describe the pressurized system halogen diode leak test.

18. Describe the hood method of helium mass spectrometer leak detection using an inflatable bag.

19. Describe the pressure decay leak test.

MATERIALS

The following equipment and materials are required to support this module:

A. Bubble Test
   1. Air compressor, air pump or other compressed air source
   2. Bubble solution
   3. Piping, tubing, valves, fittings and adapters necessary to construct a small enclosed system with a test connection
   4. Pressure gage (0-50 psi range)
   5. Assorted wrenches for tightening fittings and adaptors.
   6. Bell Jar or other test chamber fitted for a pressure test.

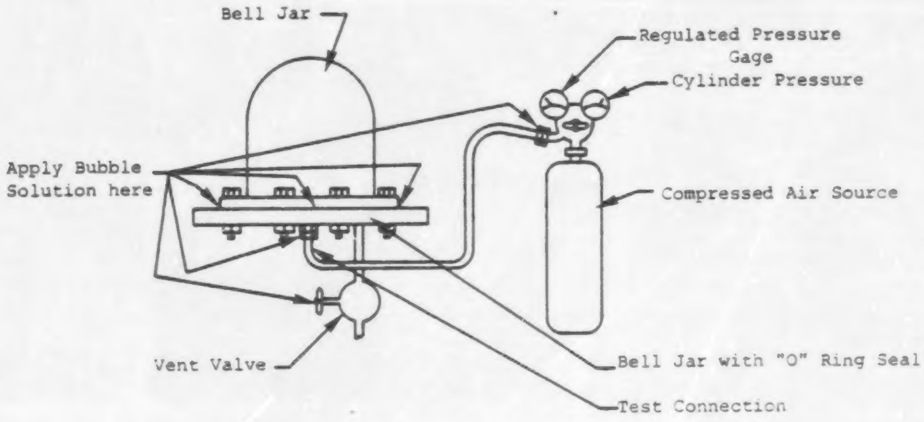
B. Helium Mass Spectrometer - Probe Method

1. Helium Gas Bottle
2. Calibrated Leak in range of 1×10^{-6} to 1×10^{-10} atm-cc/sec
3. Helium mass spectrometer
4. Probe, hose, and fittings
5. Assorted wrenches for tightening hose connections
6. Supplier's equipment manual for the helium mass spectrometer.

PROCEDURES

The following procedures are in reference to Exercise #1 and #2 of this module. If facilities are unavailable for these tests, a tour of a testing laboratory may be substituted for these particular exercises.

1. Bubble Test Procedure
    a. Assemble a closed system similar to that in the following sketch:


Bell Jar
Regulated Pressure Gage
Cylinder Pressure
Apply Bubble Solution here
Compressed Air Source
Vent Valve
Bell Jar with "O" Ring Seal
Test Connection

b. Connect the compressed air source to the test connection, close the vent valve and pressurize the system to 5 psi.

c. Observe the pressure gage for 1 minute. If pressure decay occurs, recheck all connections for tightness. If pressure still decays, accomplish steps g through k to execute repairs.

d. Pressurize the system to 30 psi.

e. After a 15 minute time at 30 psi, apply the bubble solution to all connections and to valve stems.

f. Observe for evidence of leakage. Mark each area of leakage. If there is no leakage, go to step l. If there is leakage, go to step g.

g. Slowly open the vent valve and depressurize the system.

h. Ensure vent valve is fully open and pressure gage indicates that the system is depressurized.

i. Disconnect those connections which were marked as leak sources and visually inspect them for potential causes of leaks. Look for dirt, broken threads, missing or damaged "O" rings or seals.

j. Repair or replace the leaking components and reassemble the enclosed system.

k. Repeat steps b through f.

l. Slowly open the vent valve to depressurize the system.

m. Open vent valve fully. Determine from the instructor if the system is to be left in-tact or dismantled.

2. Helium Mass Spectrometer - Probe Method Test

a. Turn power on to the helium mass spectrometer. Allow warm-up time as recommended by the manufacturer prior to performing step c.

b. Connect the sniffer probe to the helium mass spectrometer with appropriate hose and fittings in accordance with the supplier's manual.

c. Determine detector sensitivity as follows:
   - select detector range to the range in which a background reading occurs.
   - record background reading.
   - set detector range to power of ten as for the standard leak.
   - probe standard leak and record reading.
   - calculate sensitivity: $S = \frac{CL}{MR - BG}$

   (Note: sensitivity should be about 1×10^{-9} atm-cc/sec/div. Consult supplier's manual for sensitivity value and method of correction).

d. Scan the standard leak with the probe to determine scanning speed and response time.

e. Probe a filled helium gas bottle.

f. Record measured leak rate.

DATA TABLE

None.

REFERENCE MATERIALS

ASME, Boiler and Pressure Vessel Code, Section V, Article 10, Leak Testing, American Society of Mechanical Engineers, New York, N.Y.

ASTM Standards, American Society for Testing and Materials, New York, N.Y.

- E 425, Standard Definition of Terms Relating to Leak Testing (Also ASME Se-425)
- E 432, Selection of a Leak Testing Method (Also ASME SE-432)
- E 479, Preparation of a Leak Testing Specification (Also ASME SE-479)
- E 498, Leaks Using the Mass Spectrometer Leak Detector or Residual Gas Analyzer in the Tracer Probe Mode
- E 499, Leaks Using the Mass Spectrometer Leak Detector in the Detector Probe Mode
- E 515, Leaks Using Bubble Emission Techniques

NASA SP-5113, Nondestructive Testing, Chapter 9, Leak Testing, Superintendent of Documents, Government Printing Office, Washington, D.C. 20402 (Stock No. 3300-00471)

ASM, Metals Handbook Volume II, Nondestructive Testing and Quality Control, American Society for Metals, Metals Park, Ohio 44073

ASNT, Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing, SNT-TC-1A, American Society for Nondestructive Testing, New York, N.Y.

TEST

Essay

Answer the following questions as indicated.

1. a. Describe three sets of conditions under which leak testing may be accomplished.
   b. Give three general reasons for performing leak tests on systems or components.
   c. Name three fundamental conditions which promote fluid flow across system boundaries and briefly describe how each condition

2. Define or briefly describe the following:
   a. Leak
   b. Leakage
   c. Leak rate
   d. Bubble Test
   e. Pressure Change (in leak detection)
   f. Halogen Diode Detection
   g. Helium Mass Spectrometer

Answer the following questions as either true or false:

3. Vacuum chambers used in leak testing have "zero leakage". _____

4. The term leak refers to the discontinuity or passage through which a fluid flows or permeates. _____

5. Leakage refers to the fluid that has escaped through the leak. _____

6. Leak testing of systems or components is necessary for all of the following reasons: _____
   a. Prevent loss of contents
   b. Prevent containment of the working fluid

c. Detection of the unreliable components

d. Assure the maintenance of pressure differentials

7. The relative sensitivity of the following leak test methods are in the order as listed: _____
    a. Bubble Test
    b. Pressure Test
    c. Halogen Diode Detector
    d. Helium Mass Spectrometer

8. Halogen torches are not effective for measuring leak rate, cannot be used in an explosive atmosphere and when used to detect refrigerant leaks may give false indication of the leak location. _____

9. Helium mass spectrometers will also detect hydrogen, hafnium and chlorine. _____

10. The halogen diode detector works on the principle that ionized halogen atoms can produce a current that can be detected by electronic circuitry. _____

11. Pressure loss leak testing and differential pressure testing rely on the ideal gas laws. The ideal gas laws relate pressure, temperate and volume. _____

12. Water vapor in a test medium can affect the accuracy of the results. _____

13. Mass spectrometers provide high sensitivity leak testing. The gas ions are accelerated by a voltage or magnetic field and "tuned" so that a given mass strikes a target. The current flow caused in the _____

the electronic circuitry is directly proportional to the concentration of gas ions and may be appropriately displayed as a leakage rate.

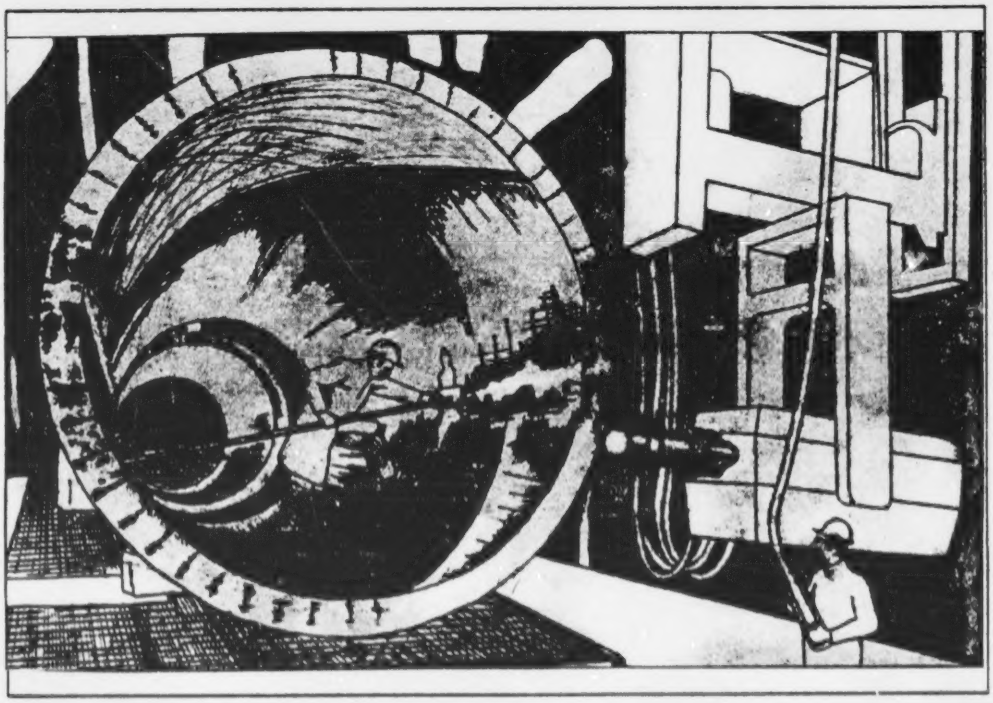
14. Unclean surfaces can mask leaks and prevent proper _____ leak detection.

15. The pressure decay leak test uses air at dew point _____ temperature and is accomplished by recording differences in ambient and dew point temperatures after successive temperature readings. The pressure remains constant during this test.

NUCLEAR TECHNOLOGY

MODULE 26 - 3

HYDROSTATIC TESTS



COURSE 26: NONDESTRUCTIVE EXAMINATION (NDE)

CORD

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

4800 LAKEWOOD DRIVE WACO, TEXAS

COURSE 26 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES I

MODULE 26-1	Visual Tests
MODULE 26-2	Leak Tests
⇨ MODULE 26-3	Hydrostatic Tests
MODULE 26-4	Liquid Penetrant
MODULE 26-5	Fundamentals of Radiography
MODULE 26-6	Radiograph Inspection
MODULE 26-7	Radiographic Specifications and Code Requirements

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INTRODUCTION

The Nuclear QA/QC technician can have responsibilities with respect to hydrostatic testing in planning for or monitoring the tests. Specific tasks include (1) initial drafting of test procedures, (2) review of test procedures for compliance with codes, specifications and standards, and (3) monitoring the conduct of hydrostatic testing.

Hydrostatic testing provides a means of determining that pressure retaining systems do not leak excessively at design pressure. The test uses the characteristics of water at rest, i.e., in equilibrium. It is relatively simple and inexpensive although safety precautions apply.

Both individual components and complete systems are hydrostatically tested. Individual components are normally tested by the manufacturer of the component. Systems are tested at the close of the construction phase of the power plant and prior to operating the plant. Also, systems and components are tested periodically throughout their service life.

This module describes the principles and practices associated with any hydrostatic test. However, because system hydrostatic testing is more complex, primary emphasis is given to testing at the power plant site.

MODULE PREREQUISITES

Prior training or experience in leak testing is required for this module. Completion of Nuclear Technology, Module 26-2, Leak Tests, satisfies this prerequisite.

OBJECTIVES

1. Describe fundamental principles associated with hydrostatic testing including the effects of compressibility, Pascal's law, gases, and temperature.
2. Draw a simplified diagram of a typical hydrostatic testing system, label test equipment and describe the function of each type of equipment.
3. Describe the role or purpose of the prerequisite when given any of nine prerequisites for system hydrostatic testing.
4. Describe the role of these elements of the written hydrostatic test procedure: title, applicability, prerequisites, main body, acceptance criteria and check off lists.
5. Describe techniques for ensuring any of the following: system boundary isolation, complete venting, protection from altering system line up during hydrostatic testing, and removal of temporary supports and connections.
6. Name three attributes which are inspected during hydrostatic testing and discuss the purpose of each.
7. Discuss a pneumatic pressure test with respect to (a) when it is used, (b) types of gases used, (c) application of pressure and (d) methods of inspecting for leaks.
8. State the purpose of inservice pressure tests and relate them to initial hydrostatic tests with regard to time at pressure and visual inspection techniques.

This module describes three procedures which reinforce the concepts presented. At least one procedure should be accomplished by each student/trainee. Advance preparation will be necessary for the activity selected. In this regard each procedure lists recommended materials and gives other suggestions for necessary preparations.

SUBJECT MATTER

HYDROSTATIC TESTING FUNDAMENTALS

Fundamental Principle

Hydrostatic testing uses the fundamental principle that liquids are essentially incompressible. When a closed system is completely filled with liquid, further addition of liquid greatly increases the internal pressure. Conversely, loss of liquid from a pressurized liquid system results in marked loss of pressure.

Units of Pressure

Pressure is force per unit area. Therefore, the units used for force and area establish the units for pressure. The English system uses pounds force (lbf) and square feet (ft^2) or square inches (in^2). The International system mostly uses newtons (N) and square meters (m^2) although dynes (dyn) and square centimeters (cm^2) are sometimes used. These units are illustrated as follows:

$$P = F/A = \text{lbf}/\text{ft}^2 \text{ or lbf}/\text{in}^2 \text{ (English)} \qquad \text{Equation 26-3-1}$$

$$= \text{N}/\text{m}^2 \text{ (International)}$$

$$= \text{dyn}/\text{cm}^2 \text{ (International)}$$

where:

P = pressure
F = force
A = area

Pascal's Law

Because liquids are incompressible, a force exerted on a confined fluid creates a pressure which is transmitted throughout the fluid. This fact was first deduced by Pascal in 1653 and is commonly known as Pascal's law which states:

> Pressure applied to a confined liquid (or gas) is transmitted undiminished throughout the confining vessel or system.

Effects of Gas

Unlike liquids, gases are compressible. A relatively large change in volume of a confined gas is necessary for a substantial pressure change. This relationship is expressed by the equation for the ideal gas law:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \qquad \text{Equation 26-3-2}$$

Where:

P_1 = original absolute pressure
V_1 = original volume
T_1 = original absolute temperature
P_2 = new absolute pressure
V_2 = new volume
T_2 = new absolute temperature

The significance of gas with respect to hydrostatic testing is the reservoir of energy represented by entrapped gas. When a system is completely filled and pressurized with liquid (no entrapped gas), a system rupture quickly depressurizes the system due to the incompressibility of liquids. However, if the system has reservoirs of entrapped gas, a system rupture results in a "blow down" as the gas pressure diminishes in accordance with the ideal gas law. Accordingly, it is not desirable to have entrapped gases in a component or system during hydrostatic testing.

Effects of Temperature

Temperature affects the density of fluid and therefore the volume of fluid if pressure is held constant. Thermal expansion coefficients, which are determined experimentally, vary from one type of fluid to another and they are not necessarily linear with temperature. Nonetheless, it is true with respect to practical hydrostatic testing that pressure varies in direct proportion to variations in temperature.

In the closed system during hydrostatic testing, small temperature fluctuations give relatively large changes in pressure. This is due to the incompressibility of the fluid. That is, the fluid's attempt to change volume as temperature changes is reflected as pressure changes. The relationship of temperature changes to pressure changes is dependent on volume of the system, working fluid, elasticity of the system and the temperature range. Rather than attempting to establish an exact relationship, practical application of hydrostatic testing demands that temperature be essentially constant. Therefore any heat transfer devices within the system are turned off during hydrostatic testing. Because the water supply is normally somewhat cooler than system ambient, there is a tendency for pressure increases due to thermal expansion of the water. If pressure approaches limits, water is drained from the system to lower pressure.

Basic Concepts

From the foregoing discussion, four basic concepts are derived. These concepts apply to any application of hydrostatic testing:

- filling of the component or system is accompanied by venting of gases

- pressure is raised in the filled component or system by further addition of water at any point.
- temperature of the water is held essentially constant and if thermal expansion causes undue pressure increases, water is drained from the system to counteract the temperature effects.
- leakage at any point is indicated by loss of pressure and by visible evidence of the leaking fluid.

HYDROSTATIC TESTING APPARATUS

Fluid

Hydrostatic testing of nuclear components and systems uses water as the testing medium. Water is plentiful, inexpensive, and compatible with most nuclear components and systems. For components and systems where hydrostatic tests with water cannot be performed, pneumatic pressure tests are substituted as described later in this module.

Apparatus

Hydrostatic testing is relatively simple and little test equipment is required. Each hydrostatic test uses essentially the same types of equipment. As illustrated in the simplified diagram of Figure 26-3-1, there are five types of basic equipment; water supply, hydro-pump, vents and drains, pressure gages, and relief valves.

Water Supply

The quality of the water used for hydrostatic testing is determined by the requirements applicable to the component or system being tested. For components and systems which supply or can supply water to the reactor during plant operations, strict cleanliness conditions are applicable

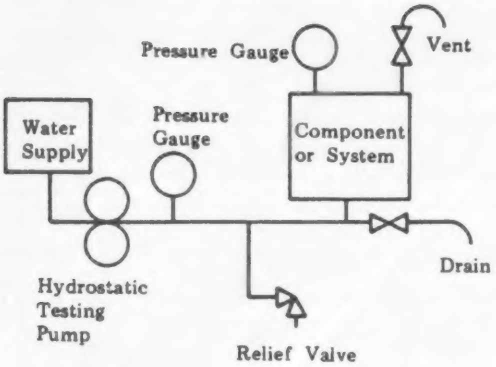

Pressure Gauge
Vent
Water Supply
Pressure Gauge
Component or System
Drain
Hydrostatic Testing Pump
Relief Valve

Figure 26-3-1. Simplified Diagram of Hydrostatic Testing System

to avoid the introduction of materials which can become radioactive during reactor operation. For other components and systems, cleanliness requirements are based on maintaining the functionability of the components and systems. Within this framework, engineering specifies one of the following sources of water for hydrostatic testing: (1) demineralized water, (2) potable water, or (3) fire main water.

- demineralized water - Demineralized water is essentially pure in that its conductivity is 3 micromho/cm or less, its pH is about 7.0 and its halogens are less than one part per million. Demineralized water is used for hydrostatically testing reactor systems or for flushing such systems after hydrostatic tests with lesser quality water.

- potable water - Potable water is from the sources of drinking water. It is used in hydrostatically testing all other components and systems unless fire main water is used.
- fire main water - The quality of fire main water varies widely from plant to plant. When it is essentially of potable grade, it is frequently used for hydrostatically testing non-reactor systems.

Hydrostatic Testing Pumps

Pumps used for hydrostatic testing are positive displacement pumps. This class of pump forcefully adds a given quantity of water on each cycle of the pump. Thus, it is capable of increasing discharge pressure to the values necessary for hydrostatic testing.

Hydrostatic testing pumps may be reciprocating, gear, or lobe pumps. The prime mover may be manual, electric, or pneumatic. The pneumatic reciprocating pump has widespread use due to its variable speed and convenient power source. In any event, the specific pump used must have a pressure rating equal to or higher than the maximum hydrostatic test pressure.

Vents and Drains

Vents serve to provide an escape route for atmospheric gases during initial fill of the component or system. To ensure complete removal of gases, vents are installed at each "high point" where gases could otherwise be entrapped. Such vents may be permanently installed or may be installed temporarily for the expressed purpose of supporting the hydro-static test. Temporary vents are removed subsequent to hydrostatic testing. Vent valves are normally manual globe valves rated at or above maximum hydrostatic test pressure.

Drain valves serve to provide an escape route for the water whenever the component or system is drained. These valves are installed permanently or temporarily at the "low points" of the component or system. They are normally manual globe valves and are pressure rated at or above maximum hydrostatic pressure.

Both vents and drains are frequently equipped with hose connections. This permits use of hoses to direct water from vents or drains to satisfactory collection points such as storage tanks or sewers. It avoids permanent piping for this purpose.

Pressure Gages

For hydrostatic testing of new components and systems, at least one direct reading pressure gage is required. If the gage is located out of view of the operator of the hydrostatic test pump, another identical gage is installed on the pump discharge for monitoring by the pump operator. Normally, bourdon tube pressure gages are used.

Each pressure gage has a range of no less than 1½ and no more than 4 times the test pressure. This range provides ample over-pressure range, uses the most linear portion of the range, and offers adequate discrimination of gage increments for readability. Each pressure gage is calibrated with a dead weight tester prior to each use or at two week intervals if it is used continuously.

Relief Valves

Relief valves provide over-pressure protection during hydrostatic testing. Relief valves may be integral with the pump such that pump discharge is returned to pump suction if the relief valve opens. Relief valves may be temporarily installed to the pump discharge or to the component or system such that pump discharge is directed to a drain if the relief valve opens. In any event, the relief valve must provide a flow rate equal to or greater than pump flow rate at the set point pressure.

Relief valves may be self-actuating or actuated by an external source such as electrical solenoid or pneumatic piston or diaphragm. For externally actuated relief, pressure sensing devices are necessary to actuate the solenoid or pneumatic controls at a predetermined set point.

Installed systems typically have a relief valve as an integral part of the system. However, the set point of such reliefs is normally lower than the maximum hydrostatic test pressure. Reliefs with such lower set points are gagged shut during hydrostatic testing.

APPLICATION

The ASME Boiler and Pressure Vessel Code, (Code) which governs pressure boundary components, requires hydrostatic testing of each component and system which is built or installed to the Code. However, nuts, bolts, studs, and gaskets are not individually tested. Instead, test of the assembled component or installed system tests these parts if they are serving in a pressure retaining capacity. In addition to Code requirements, the designer of "balance-of-plant" systems may stipulate hydrostatic testing of the installed system as one means of determining the acceptability of the system.

When components are destined to be installed into systems which require hydrostatic testing, procurement documents typically require the supplier to hydrostatically test the component prior to its delivery. This ensures that the basic component is capable of passing the test and avoids the risk of repair costs at the construction site. If hydrostatic testing of a component is delayed until the test of the entire system, failure of the component presents much more difficult repair or replacement conditions and may jeopardize the construction schedule.

At the power plant construction site, installed systems are hydrostatically tested as a portion of the owner's acceptance of the systems for operations. Because such tests of installed systems are more complex than tests of individual components, the remainder of the module deals solely with system hydrostatic tests at the power plant site.

PROCEDURES FOR SYSTEM HYDROSTATIC TESTS

Plant Conditions

As the construction of a nuclear power plant nears completion, a series of preoperational and acceptance testing is instituted by the owner. These tests determine that the plant systems function as intended and that safe and reliable plant operations can commence. One of the first of such tests is the system hydrostatic test.

Few power plant systems are completely divorced from other plant systems. Instead, there are normally interconnections among systems. Interconnected systems may have different design pressure ratings. Also, portions of a given system may have different design pressure ratings than the remainder of the system. For example, a pressure relief system may be rated up to the relief valve at higher pressure than the system it protects while downstream of the relief valves, it may be rated at a pressure lower than the system it protects. Other examples include the water supply portions of system which serve only for initially filling the system.

Because of the interconnections and due to the need for a practical schedule for conducting hydrostatic tests, either portions of a system or a single system are normally tested individually. Nonetheless, if installation is complete, interconnected systems of equal pressure ratings can be hydrostatically tested simultaneously.

Prerequisites

The owner has the responsibility of ensuring that a system is ready for hydrostatic testing. In carrying out this responsibility, the owner prearranges or accomplishes the following prerequisites:

- Compliance with nil-ductility temperature limits - For each pressure retaining system, a permissible lowest service temperature is established by impact testing of the materials used in constructing the system. The permissible lowest service temperature is the minimum temperature at which the system is pressurized. It is a value greater than the nil-ductility transition temperature and it ensures that the material is in its ductile range versus a brittle fracture range. Hydrostatic testing is always performed at a system and water temperature greater than permissible lowest service temperature in order to preclude the possibility of brittle fracture.
- Notification of Authorized Inspector - The ASME Boiler and Pressure Vessel Code requires that hydrostatic tests of systems of pipe size greater than four inches be witnessed by the Code Authorized Inspector. For small systems, the Code Authorized Inspector must review the test report. It is incumbent on the owner to make necessary arrangements with the Authorized Inspector to perform these duties.

- Exposure of welded and mechanical joints - Prior to testing, thermal insulation is not installed or is temporarily removed for welded and mechanical joints. This permits visual inspection of such joints during the hydrostatic test.
- Restraint or isolation of expansion joints - The design of expansion joints may not permit them to carry the pressure loading during hydrostatic testing. In such cases, they are temporarily restrained or isolated until completion of the test.
- Provisions for system isolation - The system or portion of system to be tested must be capable of being isolated from other connecting systems. Installed valves or temporary blank flanges of adequate pressure rating must be available for isolation purposes.
- Addition of temporary supports - When systems which carry vapor or gas in service are hydrostatically tested, the installation design of such systems often cannot support the weight of water. In such cases, additional temporary supports are used until completion of hydrostatic testing.
- Availability of written procedure - Due to the complexity of system hydrostatic testing, written procedures are prepared which give instruction on conducting the test.
- Availability of trained personnel - Personnel who conduct hydrostatic testing must be knowledgeable of the system and of testing techniques. The competence of testing personnel is certified by a company examiner based on the training and experience of each person. This helps to ensure safe conduct of the test with respect to equipment and personnel safety.

- Availability of testing apparatus - In addition to the water supply, pump, pressure gauges, hoses and connections fundamental to any hydrostatic test, the owner ensures that vents and drains exist or are temporarily installed for hook-up of the apparatus to the system. It is also good practice to have surplus fittings, seals, and gauges on hand in the event of the need to replace any of the temporary connections.

Written Procedure

A written procedure is prepared and used for each system hydrostatic test. Each procedure normally contains nine elements as follows:

- Title - The title is descriptive of the system to which the procedure applies. It includes a revision number and date and an approval signature. The title provides for individual identity of each procedure and bears evidence of being a procedure approved for use.
- Applicability - A definitive statement is made on the purpose of the procedure. The statement defines the boundaries of the system which are tested by the procedure.
- References - The source documents which establish requirements being met by the procedure are listed. This permits convenient reference to such documents whenever there is need to review the procedure for compliance with requirements. Also, if the procedural steps require work in accordance with another document or procedure, such other documents and procedures are listed. This permits convenient cross-reference with other documents and procedures.

- Prerequisites - The prerequisites for the specific hydrostatic test described by the procedure are stated. This provides a listing of conditions which are confirmed at the outset of the actual test.
- Precautions - Any precautions applicable to overall conduct of the test are listed. Precautions applicable to specific procedural steps are listed later in the procedure adjacent to the step. Precautions listed at this point are those pertaining to general safety and to possible contingencies. For example, the minimum system and water temperature for the test may be listed.
- Limitations and actions - This element calls for listing limits applicable to the overall test and actions to take if such limits are exceeded. It helps to ensure the overall safe conduct of the test. For example, this element might state "Pressure shall not exceed x lbs/in^2 at any time during the test. In the event pressure reaches x lbs/in^2 at any time, the operator shall immediately stop the test pump and open abc drain valves until pressure is reduced to designated pressure."
- Main Body - Step-by-step instructions are given in sufficient detail for trained personnel to properly conduct the test. Instructions are provided for each person who has tasks to perform. As appropriate, sequence of tasks are delineated and precautions applicable to individual tasks are stated. The main body begins with requiring confirmation of meeting prerequisites, proceeds with conduct of the test, and concludes with restoring the system to a specified condition. In other words, all necessary instructions are given for setting up the system, testing it, and restoring it to a preferred configuration and condition.

- Acceptance criteria - Specific criteria are listed by which the results of the test are deemed acceptable. For welded and mechanical joints, no visible leakage is typical. For valve seats and stems and for pump shafts, a maximum leak rate is typical. In any event, the acceptance criteria serve to provide specific limits for judging the acceptance of the tested system.
- Check off lists - Hydrostatic testing invariably involves positioning valves, making test equipment connections, and possibly adding temporary blanks, fittings and valves. The number of these manipulations makes it more convenient to use check off lists than to detail each manipulation in the procedure's main body. Check off lists are made attachments to the procedure and are made mandatory by steps within the main body of the procedure. Each check off list names specific valves, blanks, connections, and other apparatus such as electrical power switch gear and lists the position in which each item is to be placed. Normally, there are two check off lists: one for lining up the system to permit conduct of the hydrostatic test and one to place the system in the desired condition subsequent to completion of the test. In this manner, better assurance of correct line up is obtained because reliance is not placed on operator's memory of what line up exists.

Specific Techniques

While hydrostatic testing is basically a simple test, there is considerable room for error in preparing for and conducting the test. Most errors tend to be ones which physically limit the ability to pressurize the system and are, therefore, "on the safe side". Even these, however, slow the conduct of the test and needlessly add costs. The following techniques are based on experience; these should be considered whenever hydrostatic testing is performed:

- System boundary isolation - Any opening in a system prohibits pressurization if the opening is to atmosphere or it leads to unintentional stopped pressurization of another system if the opening is to another system. Such events are avoided if check off lists are complete and correct for system boundaries. A recommended technique for ensuring boundary isolation is the requirement for a review person to mark the desired boundaries of the test on the as-built drawing of the system and then review the check off list for inclusion of each boundary point. In marking the drawing, the person looks for and marks each possible escape route from the system and each connection to the system which is not to be tested by the hydrostatic test. In this manner, all interconnections, vents, drains, instrumentation lines, expansion joints, and any other boundary point are accounted for.
- Tightness of test connections - The connections of the hydrostatic test pump with the system and the connections of temporary vents, gauges, drains, or blanks to the system are potential sources of leakage. Where practicable, these connections are hydrostatically tested prior to testing the system. Where such testing is impracticable, observers are assigned to visually inspect such connections for leakage as pressure is being applied. These techniques provide for early detection of leaking connections which permit more timely correction. Also, surplus fittings, gaskets, "O" rings, etc., should be on hand for quick replacement of leaking connections which cannot be corrected by tightening the joints.

- Filling and venting - As previously described, vents are placed on system high points to vent the system during filling. To ensure adequate removal of gases, most companies have adopted a technique involving use of clear tubing connected to each vent. Operators are instructed to leave the vent open until a full stream of water without air bubbles flows through the tubing.
- Pressure gauge connections - Most instances of system overpressurization have occurred due to isolated or partially isolated pressure gauges. That is, a valve in the gauge sensing line is unintentionally left closed or partially closed. To avoid this problem, companies either require two independent checks that gauge sensing line valves are open or require installation of the gauge without valves in the sensing line. Also, it is good practice to keep the operator of the test pump advised of the closing of system vents. When the last vent is closed, the pump operator expects to see an increasing pressure indicated by the gauge, otherwise, some problem is suspected and reported.
- Tag out system - As described previously, systems are lined up for hydrostatic testing in accordance with check off lists. To guard against someone else altering the lineup for some other test or work activity, an administrative tag out system is used. Each valve, switch, breaker, and other device whose position must not be changed during the hydrostatic test is tagged. Typically, the tags used are red in color and contain the caution of "Danger-do not operate". Each tag is serialized and listed in a logbook at the time of placing tags on items. At the end of the test, each tag is checked off in the logbook as they are removed. This type of system

protects personnel and equipment from the consequences of unauthorized operation of valves, switches, breakers, etc.

- Removal of temporary items - As previously described, the conditions of a system at the time of hydrostatic testing sometimes require installation of temporary devices such as supports, valves, blanks, etc. At the conclusion of the test, these temporary devices must be removed. To ensure removal of each temporary device, one of two techniques is common. First, a check off list for temporary devices can be made part of the procedure. Secondly, a logbook can be used to record installation of each temporary device and subsequent removal.

INSPECTION

General

For each hydrostatic test, one person is designated as the lead tester who is responsible for all inspections and signing of the test report. Other testing personnel report to the lead tester on conduct of each step of the procedure including the performance of inspections.

Inspections associated with hydrostatic testing are concerned with test pressure, time at pressure, and leaks.

Test Pressure

System design specifications establish system design pressure in accordance with the ASME Boiler and Pressure Vessel Code or other design criteria. These specifications stipulate hydrostatic test pressures directly or by reference to the applicable design criteria. The hydrostatic testing procedure implements the stipulated test pressure. The lead tester is responsible for determining that the test is performed at the stipulated test pressure. In general, the systems are tested at 1.25 times the system design pressure.

Time at Pressure

The ASME Boiler and Pressure Vessel Code requires that test pressure be held for a minimum of ten minutes prior to inspection for leaks. This time provides for ample opportunity for water to seep through small leaks which may be present and thereby be visible upon inspection. The lead tester is responsible for ensuring compliance with this requirement.

Inspection for Leaks

For most system hydrostatic tests, some leakage is expected through valve seats, valve stems, and pump shafts. For this reason, inspection for leaks by pressure loss is not feasible, Instead, the system is visually examined for leakage. In general, the following criteria apply:

- no visible leaks at welded and mechanical joints.
- no visible leaks at transitions and areas of high stress.
- no visible leaks around stems and shafts where the design does not permit leakage.
- compliance with designated leak rates around stems and shafts where the design permits a specified amount of leakage.

In performing the visual inspection for leaks, visual aids may be used. For example, blotter paper may be used to determine if joints are leaking. Portable lights are normally needed for adequate visibility.

When leakage around stems and shaft seals is expected due to the design, provisions are necessary to prevent such leakage from masking other possible leakage. In some cases, permanent leakage collection systems are installed. For other instances, an acceptable technique is the temporary placement of a coffer dam around the stem or shaft and tubing for draining the leakage away from the system. When it is required to measure the leak rate from stems or shafts, this arrangement provides for easy measurement.

When required, leak rate measurements around stems and shafts and across valve seats are made by the timed collection of leakage. Permanent leakage collection systems or temporary tubing on the unpressurized side of these items permits collection of leakage in graduated containers for a timed interval. Leak rate is determined by dividing the quantity collected by the time of collection. For example, collection of 15 milliliters of water in a ten minute interval computes to a 90 mililiters per hour leak rate.

ALTERNATIVES TO HYDROSTATIC TESTING

If it is not practical to perform a hydrostatic test, a pneumatic test is performed. Pneumatic tests are performed when, (1) the system design strength does not permit safe filling with water, and (2) the system is not easily dried and traces of the test medium (water) cannot be tolerated in service.

Pneumatic testing uses nonflammable gas as the test medium. At nuclear power plants, the gas is normally compressed air although nitrogen or helium may be used. As with hydrostatic tests, the system temperature must be above permissible lowest service temperature.

Conduct of pneumatic testing is identical to hydrostatic testing except for pressure application and inspection for leakage.

Pressure is gradually increased to not more than one-half of final test pressure. After this point is reached, pressure is increased in steps of one-tenth of test pressure until the required test pressure is achieved. In this manner, added safety precautions are taken in the unlikely event of system rupture.

As with hydrostatic testing, the test pressure is maintained for a minimum of ten minutes prior to commencing inspection. Inspection is performed using a leak test method which is suitable for the test medium. For tests with air or nitrogen, the Bubble Test is normally used. For tests with helium, a helium gas leak detector with sniffer probe is normally used. In general helium is used only where leak rate must be measured.

HYDROSTATIC TESTING FOR IN-SERVICE INSPECTIONS

Pressure retaining components within each system boundary are periodically subjected to pressure tests throughout their operational life. ASME Boiler and Pressure Vessel Code, Section XI, establishes test intervals, types of tests, and acceptance criteria for these "inservice inspections". These tests determine the continued integrity of pressure retaining systems throughout the approximately 40 years of plant operation.

Basically, two types of tests are conducted at specified intervals. The second type is visual examination for leakage with the system pressurized above normal operating pressure. The exact test pressure for the second type is specified by the Code for each system classification.

The inservice pressure tests used much of the techniques previously described for hydrostatically testing new systems. However, necessary modifications are made as follows:

- time at pressure - When items hydrostatically tested are not directly accessible for visual inspection due to space restrictions or thermal insulation, test pressure is held for four hours prior to starting the inspection. This permits ample time for evidence of leakage to be present in surrounding areas, e.g., floors, or to be evident on the outside surfaces of thermal insulation.
- inspection - Thermal insulation need not be removed. Instead, the visible surfaces, normally exposed areas, and the surrounding area are visually examined.

As with testing of new systems, any item exhibiting leakage in excess of specific values is repaired or replaced. Written procedures are prepared and approved for executing repair or replacement.

EXERCISES

The following exercises reinforce the objectives of this module. Answer each of the following questions as indicated.

1. Review a hydrostatic test procedure and conduct the hydrostatic test outlined in the Procedures Section of this module. Note, a tour of a test facility is also suggested.

2. Vents are placed at each high point and left open during filling until a stream of water without air bubbles exits the vent. Entrapped gas is undesirable. Why?
3. Changes of temperature of the test medium during hydrostatic testing cause drastic pressure changes. In practice, this effect has most significance to the individual charged with maintaining test pressure. This individual must be alert for excessive pressure caused by temperature increases. Briefly discuss why.
4. Hydrostatic testing apparatus consists of water supply, test pump, pressure gages, vents, drains, and relief valves. Name the purpose of each.
5. Plant conditions require correct determination of boundary points for a given hydrostatic test. Relate the use of check off lists and marked up drawings for ensuring isolation at each boundary point.
6. Hydrostatic testing is performed with system and water temperature above permissible lowest service temperature. Why?
7. The Authorized Inspector is notified of the hydrostatic testing schedule to permit the inspector to witness the tests. Explain the inspectors duties.
8. For initial system hydrostatic tests, welded and mechanical joints must be exposed to permit direct visual examination for leakage. Why is NDE performed?
9. Expansion joints are temporarily restrained or isolated when their design does not permit application of the stresses associated with hydrostatic testing. Briefly discuss why this is done.
10. Temporary supports are added to systems which cannot support the weight of water during hydrostatic testing. Briefly discuss the importance of adding these supports.

11. A written procedure is available for each hydrostatic test. Briefly list the main items in the procedure.
12. The necessary number of vents must be in place prior to filling the system for hydrostatic testing. Why?
13. Written hydrostatic testing procedures normally contain nine elements: title, applicability, references, prerequisites, precautions, limitations and actions, main body, acceptance criteria, and check off lists. Name the purpose of each element.
14. The tag out system places tags on each item which must not be repositioned during the hydrostatic test. In this manner, undesirable operation of the item is avoided. List some precautions which should be used.
15. Removal of temporary items after completion of the hydrostatic test is ensured by either check off lists in the procedure or by use of logbooks. Explain why.
16. Inspection determines use of correct test pressure, correct time at pressure, and acceptability of any leakage. Briefly discuss the importance of these.
17. Leak rate is determined by collecting for a timed interval the leakage occurring within the interval. How?
18. Pneumatic pressure tests are substituted for hydrostatic tests for systems requiring pressure testing but which cannot be filled with water. Either system design strength or incompatibility of water with service requirements are causes for substituting pneumatic pressure tests. Explain why.
19. Pneumatic pressure tests use nonflammable gases such as air, nitrogen and helium. Bubble tests detect leaks when air or nitrogen is used as the test medium. Helium gas leak detectors are used when helium is the test medium. Explain why these now flammable gases are used during pneumatic and bubble tests.

20. Pressure is raised in increments during pneumatic testing as an added safety precaution. Describe the increments used during this pneumatic testing.

21. Inservice pressure tests are conducted at normal system operating pressure. Explain how.

22. Inservice hydrostatic tests are conducted at pressures above normal operating pressure as specified by the ASME Boiler and Pressure Vessel Code. Time at pressure is four hours if joints are inaccessible for direct visual examination. Why?

23. Inservice tests serve to confirm the continued integrity of pressure retaining systems. Visual inspection determines if leakage is occurring. Explain when repair or replacement of the item containing the leak is required.

MATERIALS

The following materials are required to support this module:

1. Hydrostatic test procedures and corresponding component or system drawing (see Procedure #1)
1. Equipment for the conduct of a hydrostatic test (see Procedure #2):
    a. pressure gage
    b. test fittings and tubing
    c. vent and drain valve
    d. relief valve (optional)
    e. water supply
    f. test pump
    g. component to be tested

PROCEDURES

1. Review a Hydrostatic Test Procedure

   a. Materials

      (1) copy of hydrostatic test procedure for each student/trainee or groups of four or less students/trainees. (Hydrostatic test procedures may be obtained from nearby industries or testing laboratories. Or if Procedure #2 is used, students/trainees could be requested to prepare a hydrostatic test procedure).

      (2) Drawing of the system or component represented by the hydrostatic test procedure.

   b. Instructions

      Review the hydrostatic test procedure against the contents of this module and answer the following questions:

      (1) How does the format agree with the nine procedural elements described by this module? List specific differences and describe your assessment of the significance of each difference.

      (2) Mark the boundary points on the drawing and compare them with the procedure. In each boundary point isolated by the procedure.

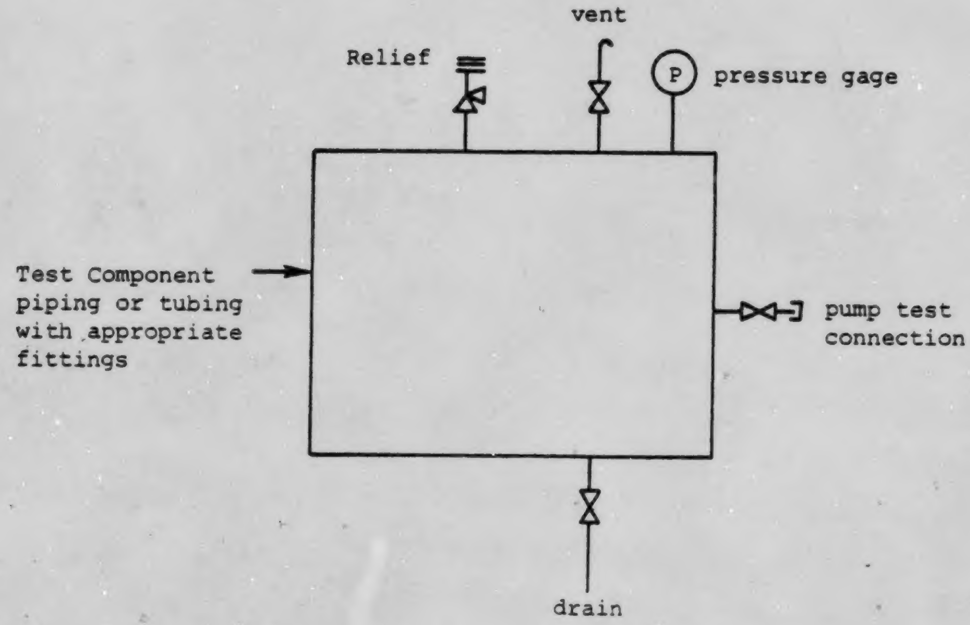
      (3) Compare the procedure with the prerequisites described by this module. Are the stated prerequisites sufficient? What would you add and why?

      (4) Visualize accomplishments of the main body of the procedure. Are there any omissions? What are they and why should they be included?

2. Conduct a Hydrostatic Test

a. Materials

(1) pressure gage
(2) test fittings and tubing
(3) drain valve
(4) relief valve (optional)
(5) water supply
(6) test pump
(7) component to be tested (a test component can be fabricated as illustrated in the following sketch).


vent
Relief
P
pressure gage
Test Component piping or tubing with appropriate fittings
pump test connection
drain

b. Instructions

(1) Obtain from the instructor the pressure rating of the component to be tested.

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(2) Prepare a hydrostatic test procedure to test the component at 1.25 times the pressure rating using the testing equipment supplied by the instructor.

(3) Obtain review of the procedure by another student/trainee.

(4) Conduct a hydrostatic test of the component using the procedure prepared in step 2.

3. Tour a Test Facility

a. Prerequisites

Completion of arrangements with a testing facility for a guided tour to observe the conduct of hydrostatic testing.

b. Objectives

Observe hydrostatic testing from initial filling through completion of inspection for leakage for the purpose of identifying the technique used.

c. Materials

Writing materials for note taking.

d. Instruction to Student/Trainee

(1) Prepare notes on the techniques used for:
  - boundary isolation
  - pressurizing to test pressure
  - time of pressurization
  - examination for leakage

(2) Subsequently, compare your notes with the contents of this module. Make a listing of techniques used by the test facility which you

consider were (a) exceptionally good and (b) somewhat poor. For each technique listed, state your reasons for classifying the technique as good or poor.

REFERENCE MATERIALS

ASME, Boiler and Pressure Vessel Code, Section III and XI, 1979, American Society of Mechanical Engineers

ANSI, Administrative Controls and Quality Assurance for the Operational Phase of Nuclear Power Plants, ANSI N18.7, American National Standards Institute

ANSI, Supplementary Quality Assurance Requirements for Installation, Inspection, and Testing of Mechanical Equipment and Systems for the Construction Phase of Nuclear Power Plants, ANSI N45.2.8, American National Standard Institute

TEST

1. State the fundamental principles upon which hydrostatic testing is based.

2. State Pascal's law.

3. Describe potential consequences of failure to vent all gases should a rupture occur during hydrostatic testing.

4. Describe the effect on pressure of a rupture during hydrostatic testing of a system which has no entrapped gases.

5. Describe the effects of temperature on hydrostatic testing.

6. Draw a simplified diagram of a hydrostatic testing system and label and state the purpose of each item of test equipment.

7. Describe the role of the following prerequisites for hydrostatic testing:
   a. Nil-ductility temperature limits

   b. Authorized Inspector

   c. Exposure of joints

8. Describe the role of the following elements of a hydrostatic test procedure:
   a. Prerequisites

   b. Main Body

   c. Check off lists

9. Describe a technique for performing the following functions in connection with hydrostatic testing:
   a. System boundary isolation

   b. Filling and venting

   c. Tag out

10. Name three inspection attributes for hydrostatic testing and state the purpose of each.
   a.

   b.

   c.

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11. Describe a pneumatic pressure test with respect to:
    a. When it is used

    b. Types of gases used

    c. Application of pressure

    d. Inspection for leaks

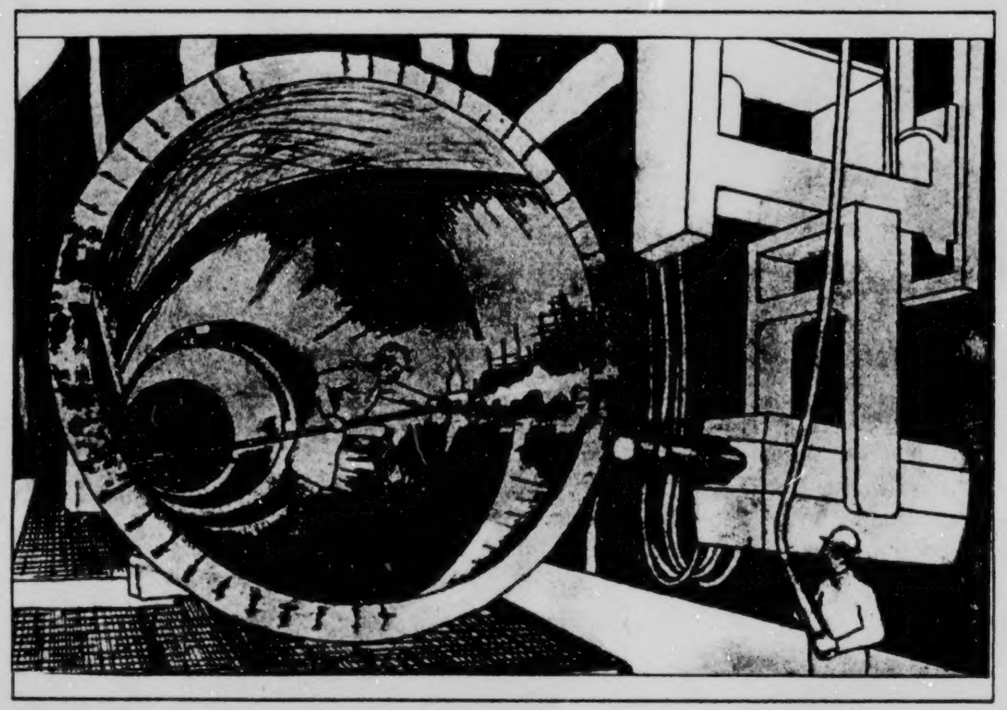
12. State the purpose of inservice pressure tests during the operations phase of the nuclear power plant.

13. Inservice pressure test is being conducted of a system which is covered with thermal insulation. How long must test pressure be applied and how would inspection be performed?

NUCLEAR TECHNOLOGY

MODULE 26 - 4

LIQUID PENETRANT



COURSE 26: NONDESTRUCTIVE EXAMINATION (NDE)

CORD

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

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COURSE 26 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES I

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INTRODUCTION

Surface of parts must not contain discontinuities which adversely affect the function or service of the part. Liquid penetrant examination provides an effective method of detecting undesired surface discontinuities which are invisible to the unaided eye. It is widely used throughout the nuclear industry.

Personnel who perform liquid penetrant examination and who establish its specific techniques are required to be certified inspectors. Certification is based on training and examination of each individual. This module parallels the training program recommended for candidates for certification.

A number of terms are introduced by this module. The student/trainee should refer to the glossary at the end of the module as each new term is encountered.

Nuclear QA/QC technicians may serve as liquid penetrant inspectors, establish test techniques, or monitor the performance of liquid penetrant examinations. This module contains ample information to support the performance of any of these tasks.

MODULE PREREQUISITES

There are no prerequisites for this module.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. Briefly describe the historical development of the liquid penetrant examination method.
2. Name the fundamental principle of operation and describe its application to liquid penetrant examination.
3. Name at least four factors affecting penetrability and discuss the effects of each.
4. List the essential steps for performing the test and describe how each step is performed when given the name of any one of three liquid penetrant methods described by this module.
5. Discuss the importance and precautions associated with the step in general or its connection with a given penetrant method when given any of the six essential steps of liquid penetrant examination.
6. Name and describe the two systems for classifying penetrants.
7. Compare the sensitivity of the three liquid penetrant examination methods described by this module in respect to rough surface, fine cracks, and shallow, open discontinuities.
8. State three advantages and two disadvantages of the method when given any of the three liquid penetrant examination methods described by this module.
9. Distinquish the terms discontinuity, indication and defect.
10. Describe the use of black light lamps including purpose, filter, darkened inspection area, darkness adaptation, and safety precautions.
11. Name three classifications of defects; given a description of product, identify typical defects and their classification.

12. State two rules with respect to the point in time where required liquid penetrant examination is performed.
13. Describe the physical, written, and operational examination criteria upon which personnel certification is based.
14. State seven items which must be included in any liquid penetrant procedure.
15. Demonstrate the capability of examining a part by liquid penetrant examination.

NOTES TO INSTRUCTOR / STUDENT

Advance preparation will be necessary for the exercises recommended by this module. In this regard, advance consideration should be given to the methods and materials to be used with regard to penetrant methods and materials, the exercises in this module suggest the use of portable test kits which are available from most suppliers of penetrants. With regard to parts to be tested, parts with surface discontinuities are preferred. Sources include weld shops, metal working shops, junk yards, scrap parts from nearby industries. Also, a decision is necessary on whether aluminum comparative test panels will be used. Aluminum alloy sheet or strip, flame heating source, and 950°F temperature melting crayon are needed to fabricate these panels. See Exercise #3.

BRIEF HISTORY OF LIQUID PENETRANT TESTING

Since the earliest uses of metals, means of detecting cracks have been explored. For many centuries, tests consisted of relatively crude methods of detecting cracks. Load tests, consisting of applied weights or pressurized fluids, determined if failure would occur at design loads. Some items, such as bells, were struck blows to determine if they "sounded right".

Nineteenth and twentieth century technology continuously placed greater demand for test methods of greater sensitivity. In the 1920's, radiography came into wide-spread use for examining metals. However, while it proved highly satisfactory for detecting internal cracks, its sensitivity to surface cracks, particularly shallow ones, was less than satisfactory. In the 1930's, Magnaflux Corporation developed and patented a magnetic particle examination method which was marketed under the trade name "Magnaflux". Their method proved highly reliable and sensitive to surface cracks. However, its application is limited to ferrous metals which are capable of being magnetized. For non-ferrous metals, detection of surface cracks depended on such methods as etching, anodizing and brittle lacquer. All of these methods depended on very careful visual examination and were not particularly sensitive to very fine or shallow surface cracks.

A forerunner of modern liquid penetrant examination was the Oil and Whiting method employed by the railroad industry. Components were soaked in hot oil which tended to enter any surface cracks. Subsequently, the component was then struck a blow or vibrated to "work" the oil out of the cracks. Oil stain on the chalk indicated the presence of cracks. This method was relatively insensitive to fine or shallow cracks.

The growth of the aircraft industry during World War II accelerated demands for more sensitive methods for detecting surface cracks. In particular, detection of fine fatigue cracks were of major concern. In the early 1940's, the work of R. C. Switzer of Switzer Brothers, Inc., led to a U.S. patent issued October 14, 1941 on the broad application of flourescent and color-contract penetrants. Later, Magnaflux Corporation in collaboration with the Switzer Brothers refined the flourescent penetrant method and obtained a U.S. patent under the trade name "Zyglo". Zyglo was quickly adopted by aircraft industries as a reliable and sensitive method of testing non-ferrous metals. Subsequently, Magnaflux Corporation and others developed the additional penetrant materials and techniques available today.

THEORY

General

Liquid penetrant examination is a nondestructive test which is capable of detecting discontinuities open to the surface of nonporous materials. It is based on the ability of a fluid to "penetrate" surface discontinuities and, subsequently, to come back out of discontinuities to form "indications". The fluids used are termed "penetrants".

Capillary Action

The fundamental principle upon which the operation of liquid penetrant examination depends is capillary action. Capillary attraction generates forces which cause a liquid to rise spontaneously in a small diameter tube. It is these same forces which cause penetrants to enter surface discontinuities. When "excess" penetrant is removed from the surface, the reservoirs of penetrant within discontinuities have a natural tendency to creep back out, thereby forming indications.

For penetration of discontinuities to occur, the penetrant must intimately contact the surface to be examined. Therefore, the surface must be clean and exposed to the penetrant. Rusts, scale, oil, grease, water, acids, dirt, lint and other foreign surface materials tend to block the penetrant from discontinuities and give high potential for not detecting all discontinuities. Coated surfaces, e.g. painted surfaces, are totally unsuitable for liquid penetrant examinations in that the coating prevents contact between the penetrant and surface.

Penetrability

The penetrability of penetrants depends on a number of factors with no single factor being solely responsible. The primary factors affecting penetrability are viscosity, surface tension, wetting ability, surface condition, and nature of the defect.

- viscocity - More than ability to penetrate, viscosity affects speed of penetration. A more viscous penetrant moves more slowly and offers more resistance to the forces drawing the penetrant into a discontinuity. However, a very fluid penetrant gravitationally drains quickly away from the surface such that a sufficient reservoir of penetrant may not remain. Penetrants have a viscosity on the order of 10 to 29 times that of water.
- surface tension - Surface tension must be relatively high for good pentrability. However, water which has a high surface tension, is a poor penetrant. Surface tensions of penetrants are on the order of ½ that of water.

- wetting ability - The ability of a penetrant to wet the surface is very important. Wetting ability is measured by the angle between the liquid and the surface at the point of contact as the liquid advances along the surface. As this contact angle decreases, wetting ability increases. Good penetrants have a very small contact angle since penetrability is directly proportional to the product of the surface tension and the cosine of the contact angle.
- surface condition - The surface to be examined primarily affects the contact angle (wetting ability) of the penetrant. The type of material, surface roughness, and cleanliness of the surface influence pentrability of a given penetrant. Manufacturers of penetrants test their products for a variety of surface conditions to determine suitability for various applications.
- nature of the defect - The width and roughness of discontinuities affect penetrability. Very tight cracks and high roughness require higher pressure from capillary action for penetration to occur. However, the natural unevenness of discontinuities tends to reduce the theoretical pressure required for penetration. Apparently, the higher capillary pressure in the tightest areas forces air out of the wider areas such that penetration results. Some penetrants have been shown to penetrate cracks as narrow as .00001 inch.

Sensitivity

Sensitivity of liquid penetrant examination refers to a qualitative measure of the ability to detect discontinuities. Numerical values are not assigned. When considering sensitivity, a number of factors must be examined. The specific type of penetrant, the surface to be examined, the nature of the discontinuities to be detected, and the specific technique employed are the primary factors affecting sensitivity. Normally, sensitivity is discussed in terms of the type of discontinuity, the relative comparison among types of penetrant, or effect of technique. For example, "sensitive to broad, shallow discontinuities"; "not sensitive to broad, shallow discontinuities"; "Type A penetrant is more sensitive to fine cracks than Type B penetrant"; "foreign surface material reduces sensitivity".

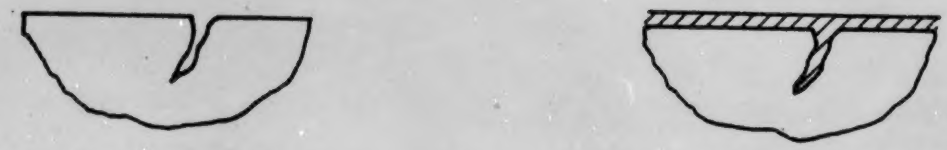
General Application

Liquid penetrant examination offers an excellent means of nondestructively examining nonporous materials for discontinuities open to the surface. If the material is porous, penetrant enters all porous areas and creeps back out as "indications" such that a meaningful examination is impossible. Therefore, liquid penetrant examination is not suitable for such materials as rubber, unglazed ceramics, wood, fibre board, paper products, etc. Instead, liquid penetrant examination is applicable to nonporous materials such as metals, glass, and porcelian.

SIX ESSENTIAL STEPS

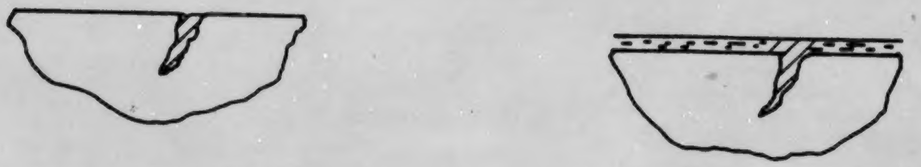
General

Each liquid penetrant examination employs six essential steps regardless of the specific type of penetrant used. These essential steps are precleaning, application of penetrant, removal of excess penetrant, developing, inspection, and postcleaning. A highly simplified illustration of the process is shown in Figure 26-4-1.



a. Clean Surface With Flaw

b. Penetrant Applied



c. Excess Penetrant Removed

d. Developing and Inspection

Figure 26-4-1. Simplified Illustration of PT Examination

Precleaning (Surface Preparation)

Precleaning activities are concerned with cleanliness and surface condition. For this reason, this essential step is sometimes termed surface preparation.

The principle of capillary attraction demands that the penetrant and surface discontinuity be in intimate contact. Dirt, oil, grease, lint, scale weld spatter, or other "foreign" matter prohibit such intimate contact and interfere with penetration. Surface coatings, such as paint, make penetration impossible. Therefore, it is essential that the surface be clean and exposed.

Selection of a precleaning method is on a case basis. Factors involved are the type of "foreign" material to be removed, the type of material and its configuration, and speed of the cleaning method. In each instance, the cleaning method must adequately clean the surface while not deteriorating or "attacking" the surface. For nickel base materials, cleaning agents must be essentially free of sulfur and for austenitic stainless steels and titanium alloys, cleaning agents must be essentially free of halogens. These agents tend to promote cracking of the metals in a temperature-stress environment.

For coated surfaces, the first step of precleaning is removal of the coating. For painted surfaces, a suitable paint remover is used. For uncoated surfaces, possible cleaning methods include detergent wash and water rinse, organic solvents, vapor degreasing, and ultrasonic cleaning. A comparison of these methods is given in Table 26-4-1.

Vapor degreasing is a preferred cleaning method for oily parts. It not only cleans the surface but, more than the other methods, removes oil from surface discontinuities. Thus penetration is aided. However, vapor degreasing will not remove rust. An intermediate cleaning method, such as pickling or hot alkaline is necessary to remove rust.

The specific cleaning method and cleaning agents must generally meet three requirements. First, it must remove oil and grease which is commonly found on surfaces from prior processing steps. Secondly, it must be free of contaminants such as sulfur and halogens. Thirdly, it must leave minimum residue on the surface.

Table 26-4-1. Precleaning Methods

Method	Soils Removed	Limitation	Remarks
Detergent Cleaning	Organic: grease, oils cutting fluids, etc. Hot alkaline is effective for inorganic scales, rusts, sands	Except for alkaline detergent cleaning and expecially hot alkaline cleaning, not totally effective for scale and rust.	Followed by rinsing and drying. Possible skin and eye irritant. Nonflammable.
Solvent Cleaning	Organic: grease, oil waxes, sealants, etc.	Ineffective for scale, rust, welding flux, and other inorganic soils.	Flammable. Possible toxic, skin irritant.
Vapor Cleaning	Preferred for organic: grease, oils, etc.	Ineffective for inorganic soils. May not remove resinous soils such as plastics, paints, varnishes.	Parts must be cooled prior to PT.
Ultrasonic Cleaning	With detergent fluid: effective for inorganic soils. With solvent fluid: Effective for organic soils.	Equipment limits to small to medium size items.	Followed by hot drying.
Paint Removal	Paints		Followed by rinsing and drying. Normally flammable. Possibly toxic skin irritant.

Grit and shot blasting and wire brushing are unacceptable cleaning methods for the liquid penetrant precleaning step. Grit or shot tends to peen the surface such that discontinuities may be closed and, therefore, prevent penetration. When grit or shot blasting is used in the fabrication processes on surfaces which must be subsequently examined by liquid penetrant, an intermediate step is added to chemically remove the blasted surface by pickling in an acid bath.

Wire brushing simply does not adequately clean the surface. Power wire brushing also has a risk of smearing metal over discontinuities such that they are not detectable.

The surface condition of concern is roughness. Excessive roughness may prohibit adequate precleaning or trap penetrant and appear as indications. Entrapment of penetrant is normally the major result of surface roughness. Therefore, a roughness limit is normally established for each method of removing excess penetrant.

Once the surface is clean and within roughness limits, the surface must be dried. Otherwise, the cleaning agent may of itself interfere with penetration. This is especially true of water since water is insoluble in many penetrants and seriously contaminates water washable penetrants. Drying is accomplished by forced hot air.

In summary, the precleaning step is essential to permit penetration. It consists of the substeps of surface preparation as necessary to remove excessive roughness, cleaning with an effective cleaning method, and drying to remove the cleaning solutions or agents.

Application of Penetrant

Prior to applying penetrant, the surface must be clean and exposed. It must be dry and free from materials from prior processing such as oil, acids and water.

Penetrants may be applied by dipping the item into the penetrant or by pouring, spraying or brushing the penetrant onto the item. When spraying is used with compressed air apparatus, a filter is placed in the air inlet line to prevent contamination by water, oil, or dirt sediment. Wiping the penetrant onto the part with saturated cloths is generally not acceptable because it tends to wipe away the penetrant. Regardless of the method employed, application of penetrant must meet the following criteria:

- temperature of the surface must be within limits - Excessively hot surfaces will evaporate the volatile constituents and leave residues which interfere with the test. When dipping is employed, parts may be as hot as about 200°F if they are allowed to cool to about ambient in the penetrant bath. Auxiliary cooling of the penetrant may be necessary if hot parts are continually dipped into penetrant. On the other hand, excessively cool parts and penetrants increase viscosity and reduce sensitivity. Therefore, temperature limits of 60°F minimum and 125°F maximum are typical.
- complete surface covering must be obtained - Application of penetrant must ensure filling of surface discontinuities. Therefore, a liberal amount of penetrant is applied over the entire surface to be examined. The examiner ensures a complete "wetting" of the surface by the penetrant. If the penetrant beads or doesn't adhere to the surface, either entrapped air (mostly in the dipping method) or foreign material on the surface are the likely culprits. Complete wetting means a liberal covering of penetrant but not submergence. When items are dipping into penetrant they are promptly removed and allowed to drain. In the event partial drying of penetrant is suspected, the part is redipped into the penetrant.

- specified penetration time must be allowed - Each type of penetrant requires some finite time to penetrate. This time is termed penetration time or dwell time. The type of discontinuity to be detected, the type of penetrant, and the temperature affect penetration time. Therefore, the optimum penetration time is established for the specific purpose of the examination, the type of penetrant used, and a specified temperature range. Dwell time ranges from 5 to 60 minutes dependent on the specific application. As dwell time increases, penetration and sensitivity increase. When tests must be conducted at temperatures lower than 60°F, long dwell times are established. Dwell time is measured from the time of application to the time of removal of excess penetrant.

Removal of Excess Penetrant

While application of penetrant purposely slops penetrant all over the surface, care is necessary in removal of excess penetrant. Insufficient removal of penetrant leaves a background of penetrant which masks, obscures, and interferes with true indications. Over-zealous removal of excessive penetrant extracts penetrant from discontinuities such that real indications may be totally removed. The success of the examination is greatly dependent on proper removal of excess penetrant.

The specific method of removing excess penetrant is dependent on the type of penetrant used as described later in this module. Regardless of the specific method used, removal of excess liquid penetrant must meet three objectives: (1) commence at the completion of the specified dwell time to allow proper penetration, (2) avoid insufficient removal of excess penetrant to preclude background indications which tend to obscure real indications, and (3) avoid excessive removal of excess penetrant to preclude removal of real indications.

Developing

Developing consists of applying a material which acts as a blotter with respect to the penetrant. As penetrant creeps out of surface discontinuities, the developer absorbs it and promotes further withdrawal of penetrant from the discontinuities. Specific developing techniques depend on the type of developer as described later in this module. Regardless of the technique, developing must meet three objectives: (1) promote visibility of indications and not obscure or mask indications, (2) obtain a thin, uniform developer coating over the entire surface being examined to ensure development of indications within any area, and (3) not result in caking, puddling, or running of the developer in order to preclude masking of indications.

Each type of developer requires some amount of time to "pull" penetrant from discontinuities. This is on the order of 5 to 10 minutes minimum.

Inspection

Inspection commences after the specified minimum developing time and must conclude prior to expiration of the maximum developing time. Otherwise, reexamination of smaller surface areas is required in order to meet these time limits.

Inspection consists of two distinct parts: interpretation and evaluation. Interpretation means a determination which classifies indications as relevant or nonrelevant. Evaluation means a determination of the acceptability of relevant indications as compared to acceptance standards.

Indications are first interpreted as relevant or nonrelevant. If indications are judged to result from a cause other than discontinuities, they are considered nonrelevant. Possible causes of nonrelevant indications include surface roughness, geometry of the part, and inadequate techniques as described below.

- surface roughness - Rough surfaces make removal of excess penetrant difficult. Penetrant can "hide-out" within the rough surfaces and appear as indications upon development. Such indications tend to be fuzzy, blotchy, or of very irregular shape. Upon removal of developer, the inspector can visually see rough areas coinciding with location of such indications. When these nonrelevant indications are so large as to give potential for masking relevant indications, the rough areas are smoothed by grinding (or other means) and reexamined commencing with precleaning. Where small indications result from known surface roughness such that relevant indications are not masked, reexamination is not required.
- geometry of the part - Sharply recessed areas tend to result in indications solely due to inadequate removal of excess penetrant. Threads, slots and sharp fillets are examples of such geometries. Since overzealous removal of excess penetrant must be avoided, some residual penetrant is expected in these recesses. Careful techniques for excess penetrant removal coupled with skilled inspection permits adequate examination of these areas. Another geometry condition which yields nonrelevant indications is the mechanical joint. For example, a gear pressed onto a shaft provides a joint into which penetrant enters just like it enters a crack. Knowledge of the construction of the surface being examined make such nonrelevant indications easily

recognized. Such indications are ignored unless such profuse bleed-out occurs as to mask areas of consideration. In such instances, the item is reexamined.

- inadequate techniques - Nonrelevant indications can occur from inadequate precleaning, insufficent removal of excess penetrant, and accidental place- of penetrant onto surfaces after removal of excess penetrant. Many soils which should have been removed by precleaning are porous. When porous soils remain on the surface, non-relevant indications occur. Inadequate removal of excess penetrant results in a "blush" type of indication over a relatively large area. Sloppy or careless work practices can transfer penetrant onto the surface after removal of excess penetrant. Potential sources include penetrant from hands, handling equipment and baskets, and work surfaces and contact of a part with an area of bleed-out on another part. Normally, nonrelevant indications from inadequate techniques are blotchy, irregular in shape, or a background blush. When such nonrelevant indications represent potential for masking or obscuring relevant indications, the part is reexamined.

Relevant indications appear as rounded or linear. Rounded indications are those where the length is no more than three times the width. This type of indication is indicative of surface porosity or inclusion of porous material on the surface. For example, gas blow holes and imbedded silicates open to the surface result in rounded indications. Linear indications are indicative of cracks, seams, laps, tears, and laminations. Such indications may range from relatively broad to very fine. Another category of discontinuities may give either rounded or linear indications. These are mostly induced flaws identified as nicks, gouges, and scratches. Also small laps and seams may give rounded indications. Sometimes, these rounded indications appear with a linear "pigtail". Finally, extremely tight cracks may appear as a series of rounded indications in a line. Such linearly disposed indications occur where bleed-out exists at various points along the crack.

All relevant indications are evaluated in terms of an acceptance standard. Typically, acceptance standards permit acceptance of the part if there are:

- no linear indications.
- no rounded indications in excess of a specified number.
- no rounded indications in excess of a specified diameter.
- not more than four linearly disposed indications where linearly disposed means those indications within a specified distance which touch a straight line connecting the center points of the outermost indications.

The acceptance standards are stated in terms of indication of size recognizing that penetrant indications are typically larger than the size of the associated discontinuity. Engineering establishes acceptance criteria based on those types and sizes of discontinuities which adversely effect the usefulness (function) of the item in service. Unacceptable discontinuities are termed defects. While each relevant penetrant indication represents a discontinuity, only those exceeding the acceptance standard represent a defect.

Post Cleaning

In most instances, items are cleaned soon after completion of inspection. The developer and penetrant as may be present typically interfere with subsequent processing or with service requirements. With either condition, post-cleaning is absolutely necessary. Even when neither of these conditions exist, items are typically cleaned for esthetics, i.e., so they do not appear dirty. Post cleaning is accomplished relatively soon after inspection because developers tend to fix on the part with time.

Any of the precleaning methods, except vapor degreasing, may be used for postcleaning. Frequently, a water rinse is adequate. Vapor degreasing is not used because it bakes the developer onto the part. If it is planned to re-examine the surface at some later time, the selected post-cleaning method must be capable of removing penetrant because penetrants in discontinuities eventually dry and are then very difficult to remove. This aspect has more importance when acceptable relevant indications must be repeated at some later time. For example, repeated tests of a test plate or repeated tests for consumer representatives.

TYPES OF PENETRANTS

Penetrants must exhibit a variety of characteristics which provide for a test that is sensitive to the types of discontinuities to be detected. In general, their sensitivity is described in terms of very fine cracks and shallow, open discontinuities because these flaws represent opposite extremes. Penetrability is extremely important for detecting fine cracks. On the other hand, ability to remain in shallow, open flaws is very important during removal of excess penetrant if such flaws are to be detected. Penetrants are formulated to meet these and other desireable characteristics insofar as possible in relation to the application intended. This means that each type of penetrant is "best" for the application for which it was formulated. Desirable characteristics include the following:

- excellent penetrability for very fine openings.
- ability to remain in coarse openings.
- highly visible.
- easily cleanable from the surface without removal of much penetrant from discontinuities.
- inert with respect to the materials to be tested.
- stable under environmental conditions associated with storage and use.
- inexpensive.
- nonhazardous.

Classification of Penetrants

All penetrants are broadly classified by their visibility into two types: flourescent and color-contrast. Flourescent penetrants contain an additive which fluoresces when struck by light of a wavelength shorter than visible light by emitting light in the visible range. Color-contrast penetrants contain a dye which is visible by both color and contrast in comparison to surroundings.

All penetrants are further classified by the method of removing excess penetrant from the surface being examined. These classifications are water-washable, post-emulsifier, and solvent removable. Each of these may be flourescent or color-contrast penetrants, although those most widely used in nuclear power plant application are water-washable fluroescent, post-emulsifier fluorescent, and solvent removable color-contrast.

Fluorescent Penetrants

Fluorescent penetrants have an additive which emits visible light when struck by higher energy light. The higher energy light is standardized as peaking at 3650 Angstroms which is just outside the visible voilet range. Dyes are selected to be responsive to this "black light," and to emit with high intensity the desired color. With the proper concentration of fluorescent dye, such penetrants are highly visible with a contrast ratio on the order of 1000 to 1.

Fluorescent penetrants in nuclear power plant applications involve the terms fluorescent color, water washable, post-emulsifier, black light, and darkness adaptation as follows:

- fluorescent color - This term refers to the color of the light emitted by the fluorescent dye and it is dependent on the type of dye. It is normally in the yellow-green spectrum because the human eye is most sensitive to this color. However, automated equipment may use fluorescent penetrants which emit another color to be most sensitive to the photomultiplier tubes.
- water-washable fluorescent penetrant - This is an oil-base penetrant with emulsifier and fluorescent dye additives. The emulsifying agent is dormant until it contacts water. When activated by water, the agent emulsifies the penetrant such that it can be washed away. The quantity of emulsifying agent is carefully controlled by the manufacturer to produce a penetrant which is removed from inspection surfaces by water spray without also quickly removing penetrant from discontinuities. Nonetheless, excess washing destroys indications. Also, this penetrant is seriously degraded if water contamination occurs.

- post-emulsifier fluroescent penetrant - This is an oil-base penetrant with fluorescent dye but without an emulsifier. Instead, an emulsifier is added at the completion of penetration time to permit washing excess penetrant with water. A finite time is necessary for the emulsifier to act on the penetrant. Emulsification times are selected which permit emulsification of penetrant on the surface but not in discontinuities. Thus, this penetrant is much less susceptable to over washing and attendant loss of sensitivity. Also, it is not so seriously impaired by water contamination as the water-washable penetrant. However, careful control of the emulsifying step is necessary.
- black light - This term is applied to the near-ultravoilet lights which are used with fluorescent penetrant examination. These lights must be sufficiently intense within the 3300 to 3900 Angstroms wave length range with little emission of light at other wave lengths. The 3300 to 3900 Angstroms wave length range is chosen because it is not harmful to living tissues. Because all types of black lights generate additional wave lengths, they are equipped with glass filters of a dense red-purple color to eliminate almost all visible light and the harmful ultravoilet waves of 3200 Angstroms and shorter. Black light should never be used without the filters or with cracked filters. Also inspectors should never look directly into a black light because temporary clouding of vision occurs in the same manner as looking into any strong light. Enclosed mercury vapor arc lamps are the most widely used black lights for fluorescent penetrant examina-

tion because they are quite capable of meeting the minimum intensity requirements. Regulated power supplies are sometimes used because line voltage fluctuations shorten the life of black lights.

- darkness adaptation - Fluorescent penetration inspection areas are purposely darkened to permit maximum visibility of indications. Upon entry to the darkened area, a person's eyes require some time to adjust to the different lighting level. Adjustment of the eyes to the lower lighting level is darkness adaptation. A minimum of five minutes should be allowed for darkness adaptation. If the inspector leaves the inspection area, another five minutes should be used upon reentry for adjusting to the darkness prior to recommencing inspection.

Color-Contrast Penetrants

Color-contrast penetrants employ a dye, usually red, which is visible by color and contrast with its surroundings. Red dyes are used almost exclusively because they give excellent color and contrast visiblity against white developers. Contrast ratios of 6 to 1 or 7 to 1 are typical.

Color-contrast penetrants are available as water-washable, post-emulsifier, and solvent removable. None require use of a black light. In nuclear power plant application, the solvent removable type is used almost exclusively.

TYPES OF DEVELOPERS

Developers are employed in liquid penetrant examination to enhance the visible evidence of penetrant indications. All developers serve as a blotter which absorbs penetrant bleeding from discontinuities. The developer spreads penetrant indications to make them more visible by more light emitted or more area for color-contrast detection. In general, developers must exhibit the following characteristics:

- good blotting action.
- easily applied.
- non-fluorescent (particularly those used with fluorescent penetrants).
- adherent as a thin coating.
- readily removable.
- inert with respect to the parts to be tested.

There are three types of developers used in nuclear applications: dry powder, water-suspension, and solvent-suspension.

Dry Powder Developer

Dry powder developer consists of light, fluffy powders which form a thin dust coating on metallic parts. Their color is typically white and they must not be fluorescent in order to avoid interference with fluorescent penetrant indications.

Dry powder developer may be used with water washable and post-emulsifiable fluorescent penetrants. It is preferred over water-suspension developer on very rough surfaces. It is applied by either dipping the part into the powder or by spraying the powder onto the part. Vibrating the part, such as by shaking and tapping, removes excess powder. After inspection, water or solvent cleaning removes the developer.

Water-Suspension Developer

Water-suspension developers are furnished as a dry powder which is mixed with water by the user in accordance with the manufacturer's directions. The concentration of the suspension greatly affects sensitivity. Excessive concentration leads to excessive coating in areas of poor drainage. Thick coatings tend to crack during the drying cycle. Insufficient concentration results in very thin coatings with less developing action. Therefore, precise mixing of the developer and agitation of tanks of the mixture are necessary.

Water-suspension developers are used with water-washable and post-emulsifiable fluorescent penetrants. It is applied by dipping the part or by hosing the developer onto the part. As with dry powder developers, the water-suspension developer must not contain fluorescent particles. It is preferred over dry powder developers on extremely smooth surfaces.

Solvent-Suspension Developers

The solvent-suspension developer is furnished premixed by manufacturers in sealed containers or pressure spray cans. Prior to use, the containers are agitated to ensure an evenly distributed suspension.

Application is by soft bristle brush or by spraying. Care is necessary to avoid running, puddling, and caking of the developer.

Solvent-suspension developer is used with the solvent-removable color-contrast penetrants. The developer solvent is highly volatile and rapidly evaporates leaving a coating of white particles which had been suspended. Prior to evaporation, the solvent tends to dissolve penetrant which is trapped in discontinuities and promotes bleed-out. The resultant white coating enhances color-contrast visibility of the red penetrant. The developer coating is removed, after inspection, by water or solvent washing.

WATER WASHABLE FLUORESCENT METHOD

Advantages and Disadvantages

The water washable fluorescent liquid penetrant examination method employs fluorescent dye and either dry powder or water-suspension developer. This method has the following advantages and disadvantages:

Advantages

- excellent visibility of indications under black light.
- readily automated.
- examines small parts (in a basket) as a unit: individual handling is required only for inspection.
- capable of examining a wide variety of shapes with equal speed.
- capable of examining rough surfaces.
- good for detecting a wide range of discontinuities.

Disadvantages

- unreliable for detecting open or shallow defects.
- susceptability of the penetrant suspension to contamination especially by water, acids, and chromates.
- susceptable to over washing with resultant loss of sensitivity.
- requires use of black light and darkened inspection area.

Apparatus

As with other liquid penetrant methods, the water washable fluorescent method can be performed entirely manually. The black light is the only apparatus absolutely necessary. However, additional apparatus is normally employed for better control, for speed, and, in some instances for automation. Such apparatus with water-suspension developer is illustrated by the block diagram in Figure 26-4-2.

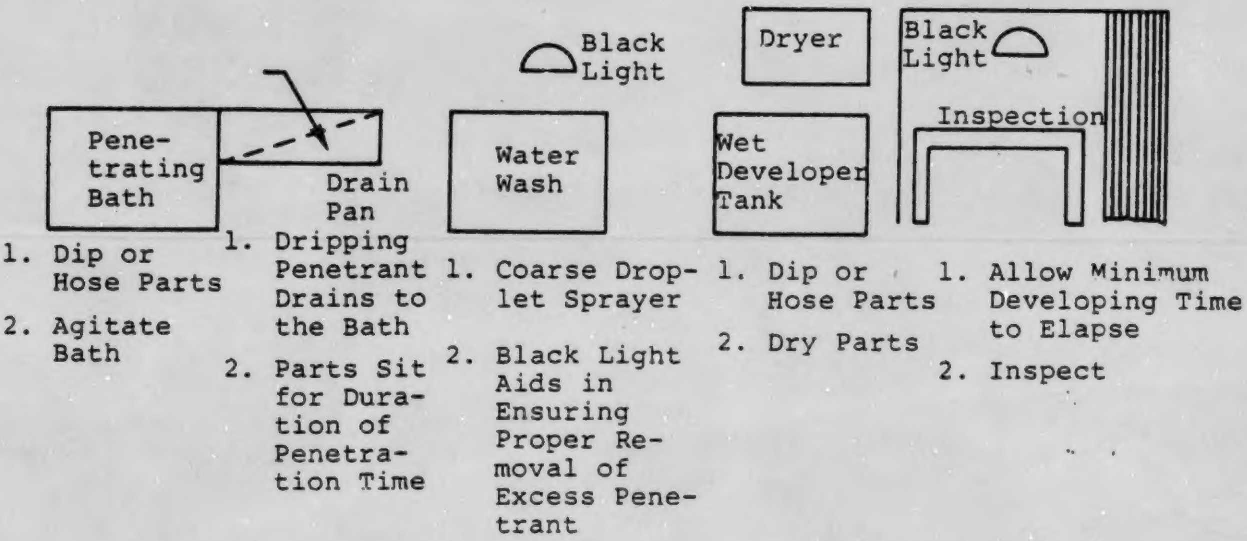

Pene-trating Bath
1. Dip or Hose Parts
2. Agitate Bath
Drain Pan
1. Dripping Penetrant Drains to the Bath
2. Parts Sit for Duration of Penetration Time
Black Light
Water Wash
1. Coarse Droplet Sprayer
2. Black Light Aids in Ensuring Proper Removal of Excess Penetrant
Dryer
Wet Developer Tank
1. Dip or Hose Parts
2. Dry Parts
Black Light
Inspection
1. Allow Minimum Developing Time to Elapse
2. Inspect

Figure 26-4-2 Block Diagrams of Apparatus for Water-Washable Fluorescent Penetrant Test

Procedure

Water-washable fluorescent penetrant examination procedures include the six essential steps previously described plus the important substep for drying. Unique factors involved with these steps are described as follows:

- precleaning - The precleaning step must avoid acid and chromate residues and must thoroughly dry the parts. Acids and chromates attack the fluorescent dye and seriously reduce the light emitted during fluorescence of indications. Therefore, if parts contacted acids or chromates in prior processing, the precleaning step must thoroughly remove them. Water used in the precleaning step must be removed by drying because water activates the emulsifier in the penetrant.

- penetrant application - Dependent on the specific application, penetrant dwell time is typically 15, 30 or 60 minutes. Thirty or sixty minutes dwell times are typically used in applications requiring detection of very fine cracks.
- excess penetrant removal - Care is necessary to avoid water contamination of the nearby penetrant tank by water spray. A coarse droplet water spray is most effective for removal of excess penetrant. This type of spray readily activates the emulsifier and pushes excess penetrant away such that minimal washing is necessary. Wash water temperatures of 90°F to 110°F provide for excellent removal of excess penetrant. However, this temperature water typically washes away penetrant in shallow, open discontinuities.
- developing - If dry powder developer is used, the parts are first dried. Water-suspension developer is applied before drying. Circulating hot-air driers are typically used for drying. Air temperature should not exceed 250°F and part temperature should not exceed 125°F in order to avoid drying of penetrant and attendent loss of sensitivity. Developing time commences with application of the developer and is typically equal to minimum penetration time. The inspector must ensure that hands, equipment, and working surfaces are free from penetrant in order to avoid nonrelevant indications.
- inspection - Inspection commences at the end of the minimum developing time. It is accomplished within

a darkened area and with a black light which has been "on" for at least five minutes to allow adequate warm-up. Black light intensity at the surface to be examined should be a minimum 800 micro-Watts per square centimeter (mW/cm^2). Measurement of black light intensity is with special light meters calibrated in units of mW/cm^2. The meter is read at the surface without a filter and then read with an ultravoilet filter which blocks all ultravoilet light. The difference between the two readings equals the black light intensity.

- post cleaning - Post cleaning is typically by water wash. When the excess penetrant removal station is used for post cleaning, care is necessary to avoid water contamination of the nearby penetrant tank..

POST-EMULSIFIER FLUORESCENT METHOD

Advantages and Disadvantages

The post-emulsifier fluorescent penetrant examination process is very similar to the water-washable fluorescent penetrant examination process except that the emulsifier is added as a separate step. The fluorescence is more brilliant and emulsification of penetrant within discontinuities is avoided. Thus, advantages are realized with post-emulsifier fluorescent penetrant although there are also disadvantages.

Advantages

- excellent visibility.
- highest sensitivity to very fine cracks.
- not subject to over washing.
- good for shallow, open discontinuities.

Disadvantages

- additional step and equipment for application of emulsifier.
- difficult removal of excess penetrant on shapes with sharp contours, e.g., screws and slots.
- difficult removal of excess penetrant on very rough surfaces.

Apparatus

With the addition of emulsifier equipment, post-emulsifier fluorescent penetrant examination employs the same apparatus as for the water-washable fluorescent penetrant process. Addition of an emulsifier tank between the penetrant drain pan and water wash station in Figure 26-4-2 produces a block diagram of a typical post-emulsifier fluorescent penetrant process.

Emulsifiers are supplied as liquids which are applied by dipping, hosing, or spraying. Application by brushing is prohibited. Brushing mixes the emulsifier to various depths of penetrant such that some emulsification of penetrant within discontinuities is likely. Application by dipping permits essentially simultaneous covering and relatively easy control of emulsification time. Application by hosing or spraying has risk of inability to control emulsification time because of the time consumed in applying the emulsifier. Multiple hoses or sprays are sometimes used in lieu of dipping in order to provide a quick means of covering the entire surface with emulsifier.

Procedure

With the exception of the emulsification step, the procedure for post-emulsifier fluorescent penetrant examination is essentially the same as for water-washable fluorescent penetrant examination. Unique features are described as follows:

- penetration time - Typically, post-emulsifier penetrants require less penetration time than water-washable penetrants. Without the included emulsifier, the penetrant can be formulated to have better penetrability. Penetration times of 5 to 20 minutes are typical with the exact time dependent on the specific application.
- removal of excess penetrant - The key step is the application of the emulsifier and the time of emulsification. At the completion of penetration time, the emulsifier is applied quickly to the entire surface being examined. The emulsifier diffuses into the penetrant at a rate dependent on the specific type of emulsifier. The time permitted for emulsification is established by trial and error during procedure qualification and is typically on the order of 1 to 3 minutes. Each application establishes emulsification time at the minimum necessary in order to avoid loss of sensitivity. Insufficient emulsification time results in inability to wash all excess penetrant and, therefore, is evident by background indications. Excessive emulsification time results in emulsifying penetrant within discontinuities, especially shallow, open ones, and sensitivity is reduced. Proper emulsification time provides for easy removal of excess penetrant without loss of sensitivity. If proper emulsification time is achieved, excess washing is of no particular concern because the penetrant within discontinuities does not have an afinity of water. Since penetrant drains unevenly from parts with sharp contours and from very rough surfaces, it is difficult to properly emulsify all surfaces of such contours. For this

reason, water-washable fluorescent penetrant is more widely used for examination of threads and key-ways and for very rough surfaces.

COLOR-CONTRAST SOLVENT REMOVABLE METHOD

Advantages and Disadvantages

The color-contrast solvent removable liquid penetrant examination process requires the simplest of equipment, no black light and no water source. Containers for penetrant, solvent and developer and clean cloths are sufficient for performing this test. These features offer the following advantages although there are also disadvantages of this method:

Advantages

- highly portable.
- employs "normal" lighting (black light, darkened inspection area, darkness adaptation are unnecessary).
- good for a variety of discontinuites.
- small initial cost.

Disadvantages

- less sensitive to very fine cracks.
- less visibility of indications.
- more difficult "housekeeping" (red dye is conspicuous, messy, and removable only with solvents).

Apparatus

Container, brushes, and cloths are all that are required although pressurized spray cans are very popular with this method. If pressurized spray cans are used for penetrant, remover, and developer, clean cloths complete the necessary apparatus. When bulk containers are used, brushes are used for application of penetrant unless the parts are dipped into the penetrant, and spray guns or brushes are used for application of the developer.

Procedure

The color-contrast solvent removable method employs the six essential steps previously described. Unique factors involved with these steps are described as follows:

- precleaning - As with other penetrant methods, thorough precleaning is necessary to remove surface materials which would otherwise interfere with the test. After cleaning and prior to application of penetrant, parts must be dry because cleaning solvents dilute the penetrant and water in discontinuities blocks penetration.
- application of penetrant - Penetrant is applied by brushing, spraying or dipping. Pressurized spray cans or brushes are most popular because only the surfaces to be inspected are wetted and it is less "messy". A liberal amount is applied to ensure complete wetting of the surface. Penetration time is typically from 5 to 20 minutes dependent on the particular application.
- removal of excess penetrant - This step and the developing step are most critical. In order to avoid excessive background indications, some solvent must be used. However, flushing the surface with solvent has high risk of removing relevent indications. Accordingly, excess penetrant is removed in two steps. First, dry cloth wipes are employed to remove visible penetrant from the surface. Then, the surface is wiped with a cloth dampened with solvent. Excess solvent in the cloth or overzealous wiping tends to remove penetrant from

discontinuities and loss of sensitivity occurs. Rough surfaces handicap removal of excess penetrant and promote more vigorous wiping to remove excess penetrant from recesses. Since this can destroy indications in smoother areas, roughness limits are normally specified for surfaces to be examined by this method.

- developing - The developer is white chalk suspended in a very volatile solvent. It is normally applied by spraying although brushing can be qualifed. Application of developer must result in a thin, uniform coating to provide for good blotting action and best contrast between the red dye and white developer. Care is necessary to avoid puddling such that the developer runs prior to evaporation of the solvent. Also, care is necessary to avoid caking, i.e., excessive thickness of the developer coating which masks indications. After application of the developer, a developing time must elapse prior to inspection. Developing time is generally ½ of dwell time.
- inspection - Inspection is carried out under sunlight or white light of sufficient intensity to ensure no loss of sensitivity. At least 30 to 50 footcandles at the surface is necessary. As with other penetrant methods, the inspection must be diligent, thorough, and cover the entire surface.
- postcleaning - After completion of inspection, the surface is cleaned with water or solvent wash or wipe. Water wash may require detergents to remove some developers.

DEFECTS

Liquid penetrant indications which are relevant and in excess of acceptance standards represent defects. In addition to reporting the existence of a defect, the liquid penetrant examiner typically must report size and type of defect. Reports of size and type of defect assist in the determination of corrective action by indicating the cause of the defect.

Penetrant examination cannot measure depth of defect. Only width and length of the indication can be reported. Linear indications are reported by length, appearance and type of defect. Terms which describe appearance are:

- sharp - Edges of the indication are well defined.
- fuzzy - Edges of the indication are ill-defined.
- smooth - Brilliance or color contrast is essentially constant for the entire length of the indication.
- fine - The indication has little width.
- broad - The indication has measurable width.
- irregularly rounded - A rounded indication with irregular circumference.
- regularly rounded - A rounded indication which approximates a circle.

Determining the type of defect represented by the indication requires knowledge of the history of the part. Each type of processing has inherent defects. Knowledge of which defects may occur helps the inspector in classifying indications.

Product history consists of three classifications: primary processing, finishing, and service. Each has characteristic defects.

Primary processing defects include all those produced by preparing material into initial useable form. This group includes defects in ingots, billets, castings, forgings, rolled product and extruded product. Characteristic defects of this group are listed in Table 26-4-2.

Table 26-4-2

Primary Processing Defects

Material Form	Defect	Typical Indication Appearance
Castings	shrinkage cracks	fine linear
	cold shuts	fine linear or intermittent linear
	handling cracks	fine or broad linear
	surface inclusion	irregularly rounded
	gas blows	regularly rounded
Forgings	laps	very fine linear or curvilinear
	tears	broad linear or curvilinear
	bursts	fine and broad linear and curvi-linear
Billets	shrinkage cracks	fine or broad linear
	seams	fine linear
Rolled Products	laps	fine linear
	laminations (open to cross-sectional surface only)	fine linear
Tubing	tears	broad linear
	seams	fine linear
	pinholes	regularly rounded

Finishing defects include all those introduced in the the manufacturer of parts. Finishing operations include forming, bending, heat treating, grinding, machining and welding. Characteristic defects of this classification are listed in Table 26-4-3.

Table 26-4-3

Finishing Defects

Finishing Method	Defect	Typical Indication Appearance
Material Upsetting (forming, bending, molding, straightening)	cracks	fine or broad linear
Heat Treating	quench cracks	fine linear, irregular pattern
	stress cracks	fine linear, irregular patter
Machining	tears	broad linear
Drawing	tears	broad linear
Grinding	cracks	fine linear
Welding	lack of fusion or penetration	fine or broad linear
	undercut	broad linear
	longitudinal and transverse shrinkage cracks	fine or broad linear

Service defects include all those which occur after the item is placed in service. These defects are typically caused by fatigue, corrosion, and stress-corrosion effects. Table 26-4-4 lists characteristic service defects.

Table 26-4-4

Service Defects

Defect	Typical Indication Appearance
fatigue crack	fine linear
stress-corrosion crack	fine linear
corrosion pitting	rounded

APPLICATION

When surface defects impair the suitability of a part, either magnetic particle or liquid penetrant examination is used to detect surface defects. Liquid penetrant examination is used for testing nonmagnetic metals such as stainless steels, nickel alloys, aluminum alloys and copper alloys.

In nuclear power plant applications, many piece parts and pressure boundary welds receive liquid penetrant examination. Requirements for these tests are found in system and component specifications and the ASME Boiler and Pressure Vessel Code. These requirements typically specify two rules with respect to the time of performing liquid penetrant examination:

- Perform liquid penetrant examination after completion of all processing which affects surface conditions. This insures that after acceptance by liquid penetrant, the surface remains unchanged.

- For installed systems, perform liquid penetrant examination after hydrostatic testing of the system. This ensures detection of discontinuities which may be propagated by the stresses from hydrostatic testing.

The liquid penetrant method employed is often inconsequential because each method has adequate sensitivity in terms of the acceptance standards. Typical application of the three methods described by this module are as follows:

- post-emulsifier fluorescent - used by reactor core manufacturers or core components where detection of shallow discontinuities are required. Some tubing manufacturers also employ this method.
- water-washable fluorescent - used by many suppliers on small parts because of the ability of this method to simultaneously test multiple parts.
- color-contrast solvent removable - essentially used in all other applications. Used almost exclusively at the power plant construction site due to its mobility. Used for inspection of welded joints.

PERSONNEL CERTIFICATION

Personnel who perform liquid penetrant examination, evaluate its results, and determine its applications are qualified in accordance with SNT-TC-1A, Recommended Practices for the Certification of Nondestructive Examination Personnel. SNT-TC-1A provides for three levels of certification which are comparable to typical job categories with a company's organization. These levels are:

- Level I - A Level I individual has sufficient training and experience to perform the test.
- Level II - A Level II individual is able to direct and carry out tests, set up equipment, interpret indications, and evaluate indications to applicable codes and specifications.
- Level III - A Level III individual is able to establish techniques, interpret codes and specifications, and designate particular tests methods and techniques to be used.

Supplement D to SNT-TC-1A describes recommended training programs for equipping candidates to become certified as Level I or Level II in liquid penetrant examination. The content of this module is comparable to the Level II training program.

Certification of Level I and II personnel is based on training experience and examination of each individual. Each company prepares a written practice which defines the prerequisite criteria for certification. Normally, the Level III examiner is responsible for determining if Level I and II candidates meet the certification criteria and for administering the certification examination.

Certification examination consists of physical, written, and operational examinations. Certification criteria typically consists of the following for liquid penetrant Level I and Level II certification:

- physical - Natural or corrected near distance visual acuity such that the applicant can read Jaeger Number 1 letters at 12 to 20 inches, or an equivalent near distance visual acuity test. Normal color perception using a medically approved color discrimination test.

- written - An 80% grade on a two part written examination. Part I examines knowledge of test principles. Part II examines knowledge of equipment, operating procedures and test techniques encountered in the candidate's specific job assignment.
- operational - Successful demonstration of performing the test and evaluating the results.

All certified personnel are required to annually repeat the physical examination for visual acuity. In addition, recertification every three years is required. Recertification may be based upon either continual satisfactory performance or re-examination.

LIQUID PENETRANT PROCEDURES

Whenever liquid penetrant examination is to be performed, a procedure is prepared and demonstrated as a satisfactory test for the particular application. Unless unique conditions exist, a given procedure is useful for a number of applications. In general, a given procedure is useful in applications where none of the following conditions are changed:

- prior processing does not include grit or sand blasting or acid cleaning.
- precleaning method is suitable for the expected types of "dirt" to be cleaned.
- same "family" of penetrant materials is used (Family of materials refers to the specific penetrant, developer and emulsifier when used which are mutually compatible as identified by the manufacturer of the materials).

Level II personnel may be responsible for drafting liquid penetrant examination procedures. Level III personnel are normally responsible for approving each procedure. In any event, each procedure must include the following:

- brand name and specific types of test materials including an applicable penetrant, penetrant remover, emulsifier, and developer.
- details of the precleaning method including cleaning materials, method of drying, and time allowed for drying.
- details of the method of penetrant application, the dwell time and the temperature limits.
- details of the method of removal of excess penetrant and drying the surface. If applicable, details of applying an emulsifier and emulsification time.
- details of applying developer, the developing time, and drying when water-suspension developer is used.
- reference to applicable acceptance standards.
- details of the post-cleaning method.

Once the procedure has been prepared, it is demonstrated by testing a part with known discontinuities in accordance with the procedure. Scrap parts or specially prepared test piece are used for demonstrating the effectiveness of the procedure. A widely used test piece is an aluminum panel prepared as follows:

- material - 3/8" thick aluminum alloy, type 2024-T-3, sheet or strip.
- site - 3 x 2 inches with the 3 inch dimension in the direction of rolling.
- preparation
  - mark the center of the top face with 950°F temperature melting crayon.

- heat the center of the underside with gas burner or flame such that crayon marking melts in about four minutes.
- immediately quench the panel in cold water.

An aluminum panel prepared in the foregoing manner contains quenching cracks which serve as a good test of the sensitivity of liquid penetrant examination. Sometimes a transverse 1/16" x 1/16" center groove is cut in the panel to provide for two test surfaces such that two types of penetrant can be compared.

GLOSSARY

- angstrom unit, A - a unit employed to express wavelengths of light, that is, electromagnetic radiation. It is equal to 10^{-8}cm.
- background - the surface of the test part upon which the indication is viewed. It may be the natural surface of the test part, or it may be the developer coating on the surface. This background may contain traces of unremoved penetrant, fluorescent or visible, which if present, can interfere with the visibility of the indication.
- black light - light in the near ultravoilet range of wavelength (3200 to 4000 A), just shorter than visible light.
- black light filter - a filter that transmits ultravoilet radiation (3200 to 4000 A wavelength) while suppressing the transmission of the visible.
- bleedout - the action of the entrapped penetrant in spreading out from surface discontinuities to form an indication.

- blotting - the action of the developer in soaking up the penetrant from the surface of the discontinuity, so as to cause maximum bleedout of the liquid penetrant for increased contrast and sensitivity.
- capillary action - the tendency of liquids to penetrate or migrate into small openings, such as cracks, pits, or fissures.
- clean - free of interfering solid or liquid contamination on the test surface and within voids of flaws.
- contrast - the difference in visibility (brightness or coloration) between an indication and the surrounding surface.
- darkness adaptation - the adjustment of the eyes, when one passes from a bright to a darkened place.
- defect - a discontinuity that interferes with the usefulness of a part.
- developer - a material that is applied to the test piece surface after the excess penetrant has been removed and that is designed to enhance the penetrant bleedout to form indications. The developer may be a fine powder, a solution that dries to a fine powder, or a suspension (in solvent or water) that dries leaving an absorptive film on the test surface.
- developer, dry - a dry, fine powder developer that is applied to the test piece after the excess penetrant is removed and the surface dried, in order to increase the bleedout by means of capillary action.

- developer, solvent - a developer consisting of fine particles suspended in a volatile solvent. The volatile solvent helps dissolve the penetrant out of the discontinuity and bring it to the surface. It then dries out, fixing the indication.
- developer, wet (aqueous) - a developer usually supplied in dry form which is mixed with water to form a suspension of particles for use.
- developing time - the elapsed time necessary for the applied developer to bring out indications from penetrant entrapments.
- discontinuity - a material void condition abruptly departing from the normal surface homogeneity.
- drain time - that portion of the dwell time during which the excess penetrant, emulsifier, detergent remover, or developer drains off of the test piece.
- drying oven - an oven used for drying rinse water from test pieces.
- drying time - the time allotted for a rinsed test piece to dry.
- dwell time - the total time that the penetrant or emulsifier is in contact with the test surface, including the time required for application and the drain time.
- emulsification time - the period of time that an emulsifier is permitted to combine with the penetrant prior to removal. Synonymous with emulsifier dwell time.
- emulsifier - a liquid that combines with an oily penetrant to make it water-washable.
- emulsion - a dispersion of fine droplets of one liquid in another, which can be stabilized by the addition of an emulsifier.

- etching - a cleaning process for the controlled removal of surface material by chemical agents prior to penetrant application.
- evaluation - process of determining the severity of the condition after the indication has been interpreted. Evaluation leads to determining whether the part is acceptable, salvageable, or rejectable.
- family - the complete series of materials necessary to perform a specific process of penetrant inspection.
- fine crack - a discontinuity in a solid material with a very fine opening to the surface, but possessing length and depth greater than the width of this opening; usually depth is many times the width.
- flaw - See defect.
- fluorescence - the emission of visible radiation by a substance as the result of, and only during, the absorption of black light radiation.
- indication - that which marks the presence of a discontinuity, as the result of detectable bleedout of penetrant from the discontinuity.
- inspection - visual examination of the test piece after completion of the penetrant processing steps.
- interpretation - the determination of the significance of the indications from the standpoint of whether they are relevant or nonrelevant.
- nonrelevant indication - an indication that is not or cannot be associated with a discontinuity.
- penetrant - a liquid capable of entering discontinuities open to the surface, and which is adapted to the inspection process, by being made highly visible in small traces. Fluorescent penetrants fluoresce brightly under black light and visible

penetrants are intensely colored to be noticeable under visible light.

- penetrant, fluorescent - an inspection penetrant that is characterized by its ability to fluoresce when excited by black light.
- penetrant, post-emulsifiable - a penetrant that requires the application of a separate emulsifier to render the surface penetrant water-washable.
- penetrant, visible - a penetrant that is characterized by an intense visible color, usually red, that allows it to give contrasting indications on a white developer background.
- penetrant, water-washable - a penetrant with built-in emulsifier, which makes it directly water-washable.
- penetration time - See dwell time.
- post cleaning - the removal of penetrant inspection material residues from the test piece after the penetrant inspection process is completed.
- post-emulsification - a penetrant removal technique employing a separate emulsifier.
- precleaning - the removal of surface contaminant or smeared metal from the test piece so that it cannot interfere with the penetrant inspection process.
- rinse - the process of removing liquid penetrant inspection materials from the surface of an item by means of washing or flooding with another liquid, usually water. Also termed "wash".
- self-emulsifiable - describes a penetrant that spontaneously emulsifies into water, a property that allows it to be rinsed off with water with more control that if it actually dissolved in the rinse water. Also called "water washable". (See also penetrant, water-washable.)

- shallow discontinuity - a discontinuity open to the surface which possesses little depth in proportion to its width.
- solvent action - the ability of a liquid to dissolve another material.
- solvent remover - a type of volatile liquid that can dissolve penetrant and that is used to remove excess surface penetrant from test parts by appropriate hand-wiping techniques.
- temperature envelope - the temperature range over which a particular penetrant inspection test will operate.
- water tolerance - the amount of water that a penetrant or emulsifier can absorb before its effectiveness is impaired.
- water-washability - the property of a penetrant which permits it to be cleaned from the surface of a part by washing with water.
- water-washable penetrant - a type of penetrant which incorporates an emulsifier, thus giving it water-washability.
- wetting action - the ability of a liquid to spread out spontaneously over and adhere to solid surfaces.

EXERCISES

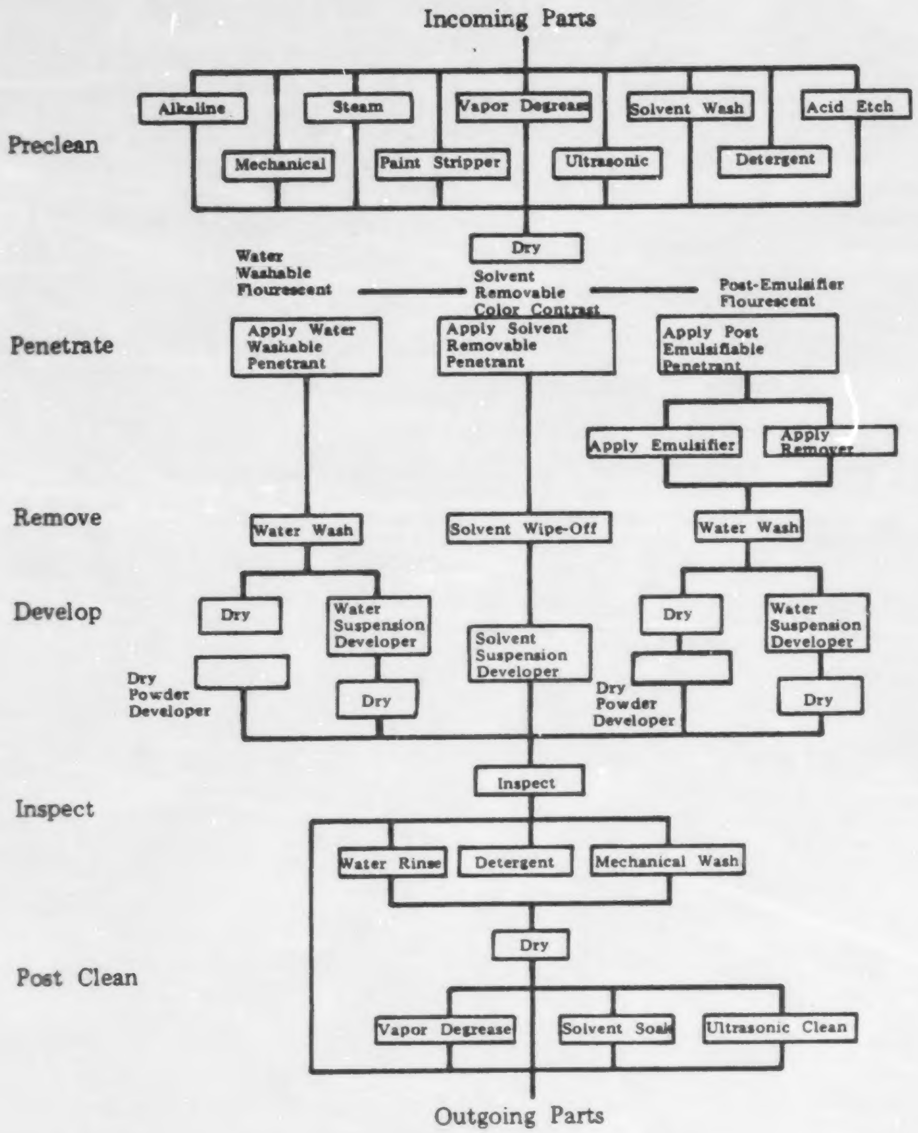
The following exercises serve to reinforce the concepts presented in this module.

1. Perform the Color-Contrast Solvent-Removal Penetrant test described in Procedure #1 of the Procedures section of this module.

2. Using Procedure #2, perform the Fluorescent Penetrant Test discussed in the Procedures section of this module.

3. Using Procedure #3 perform the preparation of an Aluminum Test Panel as described in the Procedures section.

4. Study the following block diagram and briefly explain the features associated with each method of liquid penetration examination.


Incoming Parts
Preclean
Alkaline
Steam
Vapor Degrease
Solvent Wash
Acid Etch
Mechanical
Paint Stripper
Ultrasonic
Detergent
Dry
Water Washable Flourescent
Solvent Removable Color Contrast
Post-Emulsifier Flourescent
Penetrate
Apply Water Washable Penetrant
Apply Solvent Removable Penetrant
Apply Post Emulsifiable Penetrant
Apply Emulsifier
Apply Remover
Remove
Water Wash
Solvent Wipe-Off
Water Wash
Develop
Dry
Water Suspension Developer
Solvent Suspension Developer
Dry
Water Suspension Developer
Dry Powder Developer
Dry
Dry Powder Developer
Dry
Inspect
Inspect
Water Rinse
Detergent
Mechanical Wash
Dry
Post Clean
Vapor Degrease
Solvent Soak
Ultrasonic Clean
Outgoing Parts

5. Answer each of the following questions as either true or false regarding the material presented in this module.

    a.____ Liquid penetrant examination is employed for the detection of the surface discontinuities of non-porous materials. Capillary action is the basic principle of operation.

    b.____ For each application, a liquid penetrant examination method is selected which has adequate sensitivity in terms of the type and size of defects to be detected as defined by the product acceptance standards.

    c.____ Liquid penetrant examination is performed in accordance with detailed procedures by only professional engineers.

    d.____ To assist in reporting the cause of defects, three classifications of defects are defined: primary processing defects, finishing defects, and service defects.

    e.____ Primary processing defects in castings include shrinkage cracks, cold shuts, handling cracks, surface inclusions, and gas blows.

    f.____ Primary processing defects in forgings include shrinkage cracks, cold shuts, and gage blows.

    g.____ Primary processing defects in rolled products include laps, laminations, bursts, seams, and surface inclusions.

    h.____ When liquid penetrant examination is required, it is performed after all processing which affects the surface conditions and, for systems, before hydrostatic testing of the system.

i.____ The most frequently used method at the nuclear power plant construction site is the color-contrast solvent-removable method.

j.____ Personnel certification is based on physical, written and operational examination.

k.____ Liquid penetrant examination procedures must include seven elements: specific penetrant material, precleaning method, penetrant application method, penetrant removal method, developing, acceptance standards and postcleaning method.

l.____ The aluminum test panel is suitable for demonstrating the effectiveness of a liquid penetrant procedure.

MATERIALS

1. Color-contrast solvent removable penetrant portable test kit containing pressurized spray cans of penetrant, cleaner-remover, and developer.
2. Fluorescent penetrant portable test kit containing 100 watt black light and pressurized spray cans of penetrant, cleaner, and developer.
3. Ample supply of clean, lint-free cloths (about 8 per student/trainee).
4. Contact pyrometer or other device suitable for measuring surface temperature.
5. 950°F temperature melting crayons.
6. Metal buckets.

7. Bunsen burners or other flame heating source.
8. Aluminum alloy 3/8" sheet or strip.
9. Timers or wall clocks.
10. Parts to be inspected (preferably with surface defects).

PROCEDURES

1. Color-Contrast Solvent-Removable Penetrant Test
    - A. Materials
        1. Portable test kit of color-contrast solvent-removable penetrant containing:
            - a. penetrant
            - b. cleaner-remover
            - c. developer
            - d. brush
        2. Clean, lint-free cloths (about 4 per student/trainee)
        3. Timer (wall clocks or wrist watches are suitable)
        4. Contact pyrometer or other temperature measuring device
        5. Parts to inspect (parts known to contain surface discontinuities are preferred)
    - B. Procedure
        1. Clean part by spraying with cleaner-remover and wiping with a clean cloth.
        2. Allow part to dry for three to five minutes.
        3. Measure temperature of the part. If it is between 60°F to 125°F, preceed. If not, warm or cool the part as necessary to stay within 60°F and 125°F.

4. Spray penetrant on surface to be examined; ensure wetting of entire surface.
5. Allow a 15 to 20 minute dwell time.
6. Remove excess penetrant by wiping with a dry cloth.
7. Spray cleaner-remover onto a clean cloth. Squeeze the cloth to extract excess cleaner-remover. Wipe the surface to be examined with the dampened cloth.
8. Immediately agitate developer by vigorously shaking the can and then spray developer onto surface. Ensure application of a thin, continuous coating of developer.
9. Allow 7 minutes for developing time.
10. Inspect the part. Make a sketch of the part identifying relative location, shape, and size of each indication.
11. Postclean the part by wiping with a dry cloth followed by spraying cleaner-remover on the part and additional cloth wipes.

C. Operational Experiment

1. If the foregoing procedure revealed indications, this optional experiment may be performed to obtain an appreciation of dwell time.
2. Commencing with precleaning repeat the previous procedure described in B but allow a one minute dwell time. That is, one minute after applying penetrant, remove the excess penetrant.
3. Compare indications with those initially detected.

2. Fluorescent Penetrant Test
   - A. Materials
     1. Portable fluorescent penetrant test kit consisting of:
        - a. portable black light (100 watt, 115 vac)
        - b. penetrant
        - c. developer (spray can or dry powder)
        - d. cleaner
     2. Clean, lint-free cloths (about 4 per student/ trainee).
     3. Timer (wall clock or wrist watch suffices).
     4. Contact pyrometer or other temperature measuring device.
     5. Parts to inspect (parts with known surface discontinuities are preferred).
   - B. Procedure
     1. Clean part by spraying with cleaner solvent and wiping with a clean cloth.
     2. Allow three to five minutes for the part to dry.
     3. Measure temperature of the part. If it is between $60^{\circ}F$ and $125^{\circ}F$, proceed. If not, warm or cool the part as necessary to maintain it within these temperatures.
     4. Spray penetrant onto surface to be examined; ensure wetting of entire surface.
     5. Allow a 5 to 10 minute dwell time.
     6. Spray cleaner liberally onto a cloth. Squeeze cloth to remove excess cleaner. Using the dampened cloth, wipe excess penetrant from the surface. If necessary, repeat this step with another cloth.

7. Immediately agitate developer by vigorously shaking the spray can and then spray developer onto the surface such that a thin coating is obtained.
8. Allow a 5 minute developing time.
9. Inspect the part under black light. Make a sketch of the part identifying relative location, shape and size of each indication.
10. Postclean the part by spraying cleaner onto the surface and wiping with clean cloths.

3. Preparation of an Aluminum Test Panel

A. Materials

1. Aluminum alloy 3/8" sheet cut into 3" x 2" panels.
2. Bunsen burner or other flame heating source.
3. 950°F temperature melting crayon.
4. Metal bucket or pail, 1 or 2 gallon capacity.
5. Stand and clamps.
6. Tongs.

B. Procedure

1. Mark the center of the upper face of the test panel with the temperature melting crayon.
2. Clamp test panel in a stand with marked surface up and suitable for applying heat source to under side of panel.
3. Fill pail with water and place it conveniently nearby.
4. Apply heat to underside of panel until crayon marking melts. Note time taken for this step.
5. Hold test panel with tongs, quickly unclamp the panel, and promptly drop the panel into the pail.

6. Wait about two minutes.
7. Remove test panel from pail.
8. Liquid penetrant test the panel in accordance with Exercise #1 or #2.
9. If there are no indications on the test panel, repeat this exercise but place the heat source closer to the panel.

DATA TABLE

None.

REFERENCE MATERIALS

American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, Specifications:

E165 Standard Recommended Practice for Liquid Penetrant Inspection Method

E270, Standard Definitions of Terms Relating to Liquid Penetrant Inspection

E433, Standard Reference Photographs for Liquid Penetrant Inspection.

American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III and V, ASME, New York, N.Y.

R.C. McMaster, for SNT, Nondestructive Test Handbook, Vol. 1, The Ronald Press Company, New York, New York, 1959.

W.J. McGonnagle, Nondestructive Testing, McGraw-Hill Book Company, Inc. New York, New York, 1961.

"Inspection of Welding". Welding Handbook, Section 1. latest edition, American Welding Society, New York.

C.E. Betz, "Principles of Penetrants", Magnaflux Corporation, Chicago, Illinois, 1963. Available from SNT.

Liquid Penetrant Testing, General Dynamics Corp. From American Society Nondestructive Testing, Evanston, Illinois 1967. PI-4-2, CT-6-2. 2 Volumes.

TEST

Match the liquid penetrant examination method with its characteristics by placing the appropriate letter from the right hand column adjacent the characteristic in the left hand column:

Characteristics

___ 1. Best for detecting shallow open discontinuities.

___ 2. Most susceptible to water contamination.

___ 3. Simplest in terms of equipment.

___ 4. Susceptible to loss of indications by water washing.

___ 5. Highest sensitivity to very fine cracks.

___ 6. Most portable.

Method

A. Water-washable fluorescent

B. Post-emulsifier fluorescent

C. Solvent-removable color-contrast

Answer the following questions:

7. Why should the water spray used in removing excess water-washable or post-emulsifier penetrant be comprised of coarse droplets at moderate pressure?
8. Name three deleterious contaminants which should be avoided with water-washable fluorescent penetrant.
9. What dry method is typically used with water-washable and post-emulsifier fluorescent penetrant methods.
10. Define darkness adaptation and explain its function.
11. Describe why emulsification time is critical with respect to the post-emulsifier fluorescent penetrant method.
12. Describe how excess penetrant is removed in the solvent-removable color-contrast penetrant method.

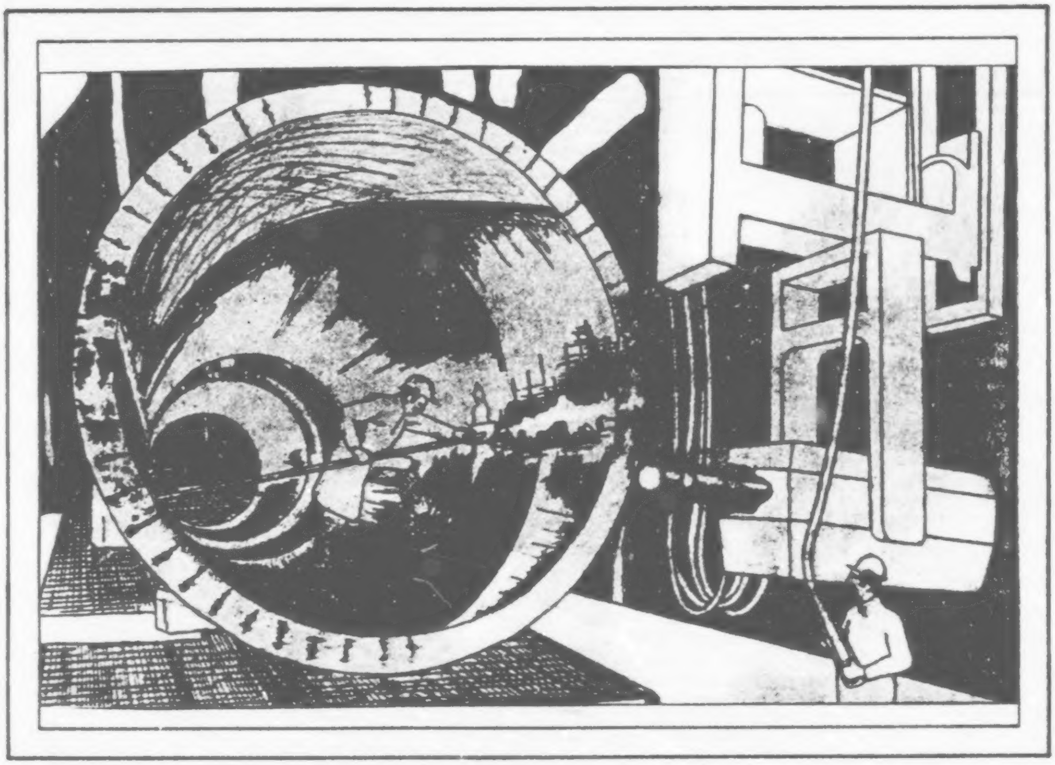
Arrange the steps listed in the proper sequence for the penetrant method and line-out steps that do not apply to the method.

13. Water-washable fluorescent penetrant method
    a. Spray solvent-suspension developer
    b. Dip item in penetrant
    c. Coarse spray water wash
    d. Vapor degrease
    e. Hose water-suspension developer
    f. Drain parts for duration of dwell time
    g. Force-air dry
    h. Inspect
14. Post-emulsifier fluorescent penetrant method
    a. Detergent clean
    b. Apply emulsifier
    c. Forced-air dry
    d. Inspect
    e. Postclean
    f. Spray penetrant onto item
    g. Dip in dry powder developer
    h. Coarse spray water wash
15. Color-contrast solvent-removable method
    a. Coarse spray water wash
    b. Solvent wash
    c. Spray penetrant onto item
    d. Inspect
    e. Spray solvent-suspension developer
    f. Dry wipe
    g. Wet wipe
    h. Apply emulsifier

NUCLEAR TECHNOLOGY

MODULE 26 - 5

FUNDAMENTALS OF RADIOGRAPHY



COURSE 26: NONDESTRUCTIVE EXAMINATION (NDE)

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
4800 LAKEWOOD DRIVE WACO, TEXAS

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COURSE 26 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES I

	MODULE 26-1	Visual Tests
	MODULE 26-2	Leak Tests
	MODULE 26-3	Hydrostatic Tests
	MODULE 26-4	Liquid Penetrant
⇨	MODULE 26-5	Fundamentals of Radiography
	MODULE 26-6	Radiograph Inspection
	MODULE 26-7	Radiographic Specifications and Code Requirements

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INTRODUCTION

Radiography is a nondestructive examination method widely used in the nuclear power industry. QA/QC technicians who are qualified in this test method are typically employed by fabricators and manufacturers of nuclear-grade components, plant constructors, electric utilities, and organizations which provide plant maintenance, modification, repair, and training services. The qualified QA/QC technicians may be responsible for one or more of the following:

- performance of radiographic test
- evaluation of test results
- witness of test
- supervision of other test personnel

Radiography is a process of testing materials that uses penetrating radiation such as X-rays or gamma rays. A photographic film is exposed to such rays that have passed through a specimen, is processed, and forms a permanent record of the resulting image. This process, thereby allows examination of the interiors of objects that are opaque to light. The basic essentials for producing a radiograph are:

- radiation source
- object to be examined
- photo-sensitive film

The radiation sources used in industrial radiography produce ionizing radiation, which may penetrate the human body and produce serious damage to cells and body tissue. Personnel working with radiation producing equipment and materials must be familiar with such radiation sources, methods of radiation detection and measurement, and the methods of controlling personnel exposure.

This module explains these concepts and describes the radiographic process, from radiation source selection, to equipment and specimen selection and arrangement, and film processing.

This module is prequisite for Module 26-6, Radiographic Inspection, which discusses specific applications and useage, and Module 26-7, Radiographic Specifications and Code Requirements, which discusses the interpretation and evaluation of radiographs.

MODULE PREREQUISITES

The student/trainee must have a background which includes general high school mathematics and Algebra I. Completion of Course 1, Radiation Physics and Course 2, Radiation Protection I are also very useful for better understanding of these module materials.

OBJECTIVES

Upon completion of this module, the student/trainee should be able to:

1. Answer correctly applicable questions on topics covered in this module as selected from the Level II SNT-TC-1A certification written test. Note: the topics and information needed to prepare the student/trainee for the SNT-TC-1A test which are not covered in this module, are covered in modules 26-6 and 26-7.
2. Answer correctly with a score of 80% or better a set of written exercises covering the following topics:
    - (a) particulate and electromagnetic radiation
    - (b) gamma radiation sources
    - (c) X-ray sources
    - (d) radioisotope source and capsule characteristics
    - (e) radioisotope cameras and accessories

    (f) X-ray machine characteristics
    (g) radiation detection and measurement equipment
    (h) equipment calibration

3. Demonstrate a knowledge of the operation and usage of radiation detection and measurement equipment by pointing out and identifying on illustrations or actual devices the various controls, and explaining the method of operation and usage in actual practice.
4. Explain the principles of radiation safety as related to time, distance, and shielding, and define the following terms: roentgen, rem, and rad.
5. Given information such as radioisotope or X-ray dose rate and shielding values, calculate:
   - emission or dose rate at a given distance
   - dose rates at different distances
   - half-value layers of shielding required to meet radiation intensity requirements at specific distances
6. Explain geometrical unsharpness as related to the location of the source, specimen, and film.
7. Define the following:
   - film contrast
   - subject contrast
   - film density
   - H & D curve
   - film speed
   - film graininess
8. Study selected specimens that are to be radiographed and specify the following:
   - source and film selection orientation and method of placement
   - penetrameter selection and usage
   - specimen identification method
   - overlap and number of exposures
   - shielding
   - use of screens and filters

9. Describe the radiographic film developing process. Outline the steps involved, and state approximate dwell times for each step.
10. Describe methods of reducing scatter.
11. Demonstrate an understanding of personnel safety and radiation protection by reviewing a sketch and description of a typical radiographic test set-up, and list the following:
    - recommended dosimetry
    - personnel precautions
    - calculated permissible "stay times" in radiation areas identified
    - effect of shielding usage specified

SUBJECT MATTER

Sources of Radiation

There are two main types of radiation: "particulate" radiation, which is composed of small particles moving through space, and "electromagnetic" radiation, which consists of very short electromagnetic waves. Both kinds of radiation convey energy through space.

Particulate radiation is the movement of subatomic particles through space. The particles of particular interest in this course are listed below with their characteristics.

Alpha:

- a particle identical with the nucleus of Helium atom (two protons and two neutrons)
- electrical charge, +2
- atomic mass, 4
- usually emitted from the nucleus of a large atom, such as Uranium
- travel at relatively low speed, through only a few centimeters in air and may be stopped by a sheet of paper

Beta:

- a particle identical to a high speed electron
- atomic mass, 1/1,840 of a proton
- emitted as either a Negatron, electrical charge -1, from a nucleus with excess neutrons, or as a Positron, electrical charge +1, from a nucleus with excess protons.
- travel at high velocities, approaching the speed of light, with a range of several feet in air, and may be stopped with a thin sheet of aluminum or a few sheets of paper.

Neutron:

- a particle with about the same mass as a proton, but with neutral electrical charge
- very penetrating, can be stopped by absorption in water, paraffin or boron
- not normally emitted in natural radioactive decay
- emitted from light elements such as beryllium and lithium when bombarded with alpha particles
- absorption by the nuclei of other elements produces radioactive isotopes.

Electromagnetic radiation consists of very short electromagnetic waves of energy having no mass or weight, moving with the speed of light (186,000 miles per second). Such radiation may be described as small packages of energy called photons or quanta. It has some properties of particles, but also has a characteristic wave motion, wavelength and frequency. For all electromagnetic radiation, the product of frequency and wavelength is a constant, and, when proper units are used, equals the speed of light. The intensity of the energy emitted depends on the frequency or wavelength of the radiation: high frequency radiation has high energy, while low frequency radiation has low energy. Two types of high energy electromagnetic radiation, gamma and X-, are used extensively in the radiographic nondestructive testing process. These are described as follows:

Gamma Radiation:

- originates in the nucleus of an atom
- emitted by the disintegration of radioactive material such as Iridium - 192 or Cobalt - 60
- highly penetrating, very high energy

X-Radiation:

- produced when a stream of fast-moving high-energy electrons are slowed down upon striking a suitable target such as tungsten
- energy level variable and controllable

Gamma Ray Sources

Radioisotopes or "sources" for industrial radiography use are available from:

- Naturally occurring materials, such as Radium - 226
- Fission products, such as Cesium - 137
- Activation from neutron bombardment, such as Iridium - 192 or Cobalt - 60.

In gamma-radiography, since all of the radioactive material in the source is producing gamma rays, the source must be as small as possible to obtain maximum sharpness of film image. The other desired characteristics for the source material are:

- appropriate gamma energy to penetrate the specimen
- high specific activity which would give small source size and high emissivity, and
- long half-life

The gamma energies emitted and half-life are physical constants for each isotope; therefore, the appropriate isotope must be selected for the particular class of work.

Several terms that have been introduced relating to radiation sources, and terms that will be discussed are defined as follows:

- Activation: the process by which neutrons bombard stable atoms to make them radioactive
- Radioisotope: an unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation.

- Gamma energy: gamma radiation emitted from radioisotopes, measured in Mev (Million electron volts)
- Specific activity: degree of concentration of radioactive material within a gamma ray source. Usually expressed as curies per gram or curies per cubic centimeter.
- Emissivity: the energy emission rate, usually expressed as Roentgen/Curie/Hour @ 1 ft. (R/Ci/Hr@1ft.)
- Roentgen: unit of exposure dose of ionizing radiation. One Roentgen (R) equals the amount of gamma or X-rays required to produce 2.5×10^{-9} coulomb of electrical charge per kilogram of dry air at standard conditions.
- Curie: basic unit of intensity of radioactivity in a sample of material. One curie (Ci) is equal to 3.7×10^{10} disintegrations per second, or approximately the activity from 1 gram of radium.
- Half-life: the length of time in which half the atoms in a radioactive substance disintegrate; the length of time required for the activity to decay to one-half its initial strength.

Table 26-5-1 lists characteristics of gamma sources most used for industrial radiography.

Encapsulation of Radioisotopes

In gamma radiography, the energy emitted from decaying nuclei is used to penetrate test specimens and expose a radiographic film. The radiography equipment must be designed to permit the gamma rays to escape, but the radioactive source material must be contained and not released into the environment where the chemicals could contact or enter the human body. This containment is accomplished by sealing the radioactive materials in small capsules - a process called "encapsulation".

The following factors must be considered in the selection of materials and designs of capsules:

- Resistance to corrosion from the radioactive material contained.
- Damage to capsule material caused by the emitted radiation.
- Resistance to high or low temperature regions in which the capsule is to be used.
- Resistance to erosion or abrasion.
- Resistance to structural stresses such as impact, vibration and fatigue loading.
- Sealing technique, e.g., silver brazing, shielded arc welding, electron beam welding, etc.
- Wall thickness of the capsule shall be as thin as practical designs allow to minimize radiation absorption by the walls.

Early capsule designs used threaded plugs, adhesives, crimping and soldering techniques for sealing which were frequently inadequate and leaked in service. Contemporary designs, however, usually incorporate fusion welding to effect a durable seal. See Figure 26-5-1, "Capsule Designs".

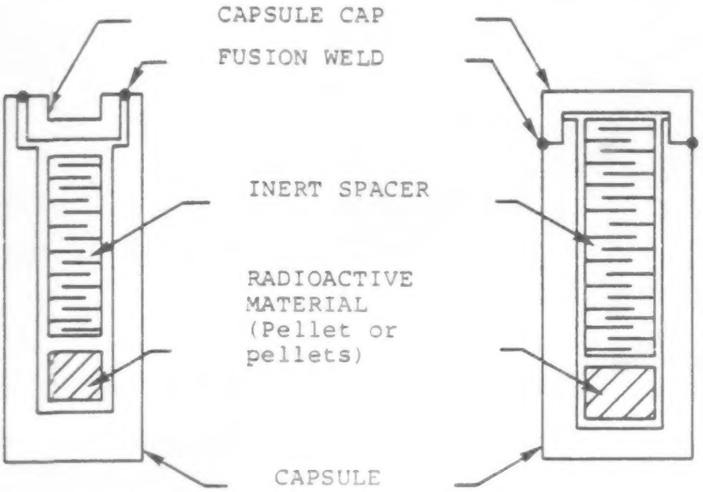

Figure 26-5-1. Capsule Designs

Metallic source pellets such as cobalt, iridium, and thulium are furnished in the shape of a right circular cylinder with typical dimensions as shown in Table 26-5-1. As the table indicates, the diameter and length are usually equal; this shape permits the use of any surface as the focal spot, since all surfaces, as viewed from the test specimen, are approximately equal in area.

TABLE 26-5-1. Typical Metallic Pellet Dimensions

Diameter	Length
1 mm.	1 mm.
1/16 in.	1/16 in.
1/8 in.	1/8 in.
1 cm.	1 cm.

Cesium and other compound type sources consist of a finely divided material which is more difficult to contain than the metallic pellets. Such sources are usually double-encapsulated, or encased in two individually sealed capsules. See Figure 26-5-2, "Double Encapsulation".

After a capsule is sealed, a leak test is required to determine if the closure is acceptable. No leakage will be permitted; if the sealing is not properly done, the by product material may escape and contaminate other equipment and the working area. Following a satisfactory leak test, the source exterior surfaces must be decontaminated and inspected carefully before being placed in service.

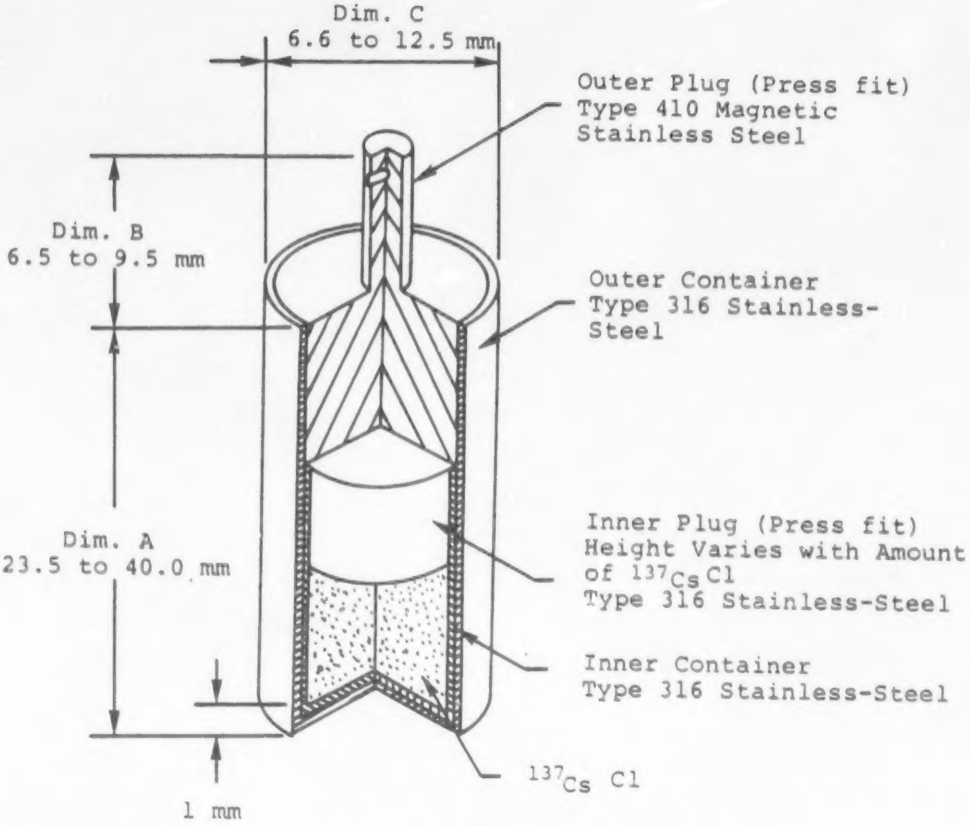
Dim. C
6.6 to 12.5 mm
Outer Plug (Press fit)
Type 410 Magnetic
Stainless Steel
Dim. B
6.5 to 9.5 mm
Outer Container
Type 316 Stainless-Steel
Dim. A
23.5 to 40.0 mm
Inner Plug (Press fit)
Height Varies with Amount of ^{137}Cs Cl
Type 316 Stainless-Steel
Inner Container
Type 316 Stainless-Steel
^{137}Cs Cl
1 mm

Figure 26-5-2. Double Encapsulation

Isotope Cameras

Isotope sources present a full-time radiation hazard and consequently, must be handled carefully, and stored and locked in shielded containers when not in use. The equipment designed to provide a means of safe handling and secure storage of radioactive source, together with a source, is referred to as a camera. A typical camera is shown in Figure 26-5-3.

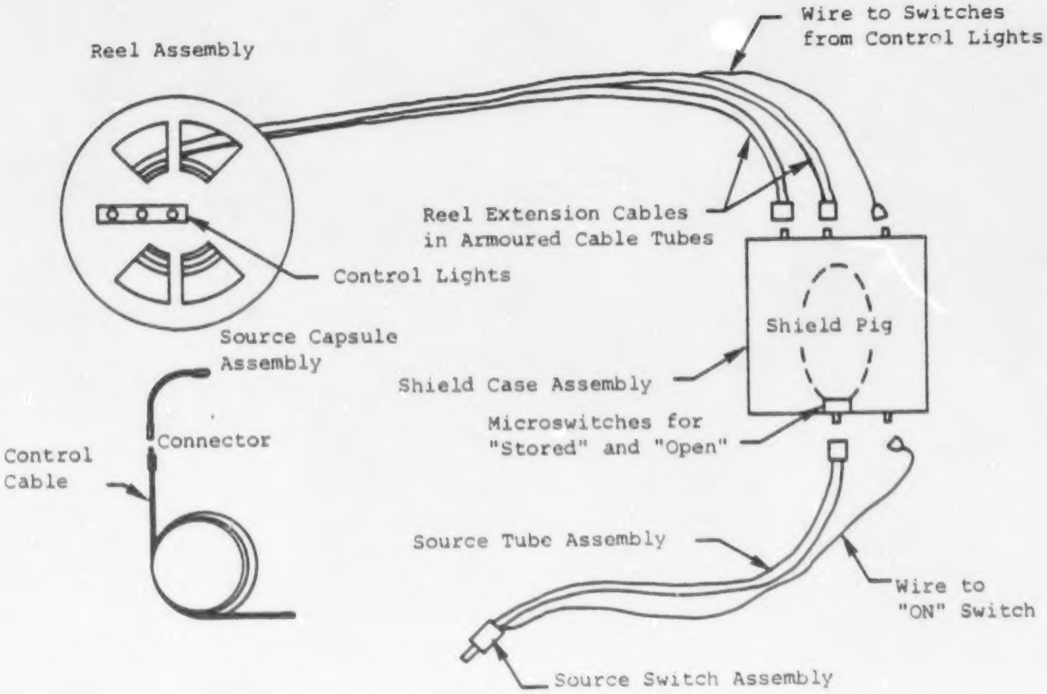
Reel Assembly
Wire to Switches from Control Lights
Reel Extension Cables in Armoured Cable Tubes
Control Lights
Shield Pig
Source Capsule Assembly
Shield Case Assembly
Microswitches for "Stored" and "Open"
Connector
Control Cable
Source Tube Assembly
Wire to "ON" Switch
Source Switch Assembly

Figure 26-5-3. Isotope Camera

The basic components of the camera are:

- Source capsule assembly: A short length of flexible cable with the source, in a stainless steel capsule, attached to one end, and with a connector for attachment to the control cable on the other.
- Shield case assembly: A heavy gage steel case containing lead or spent Uranium shielding material for storing the source capsule when not in use. One side of the case has connectors for the attachment of the control cables and the other a connector for the source tube assembly.

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- Reel assembly: A storage reel for the flexible armored steel cables, a crank to extend and withdraw the source, and control lights to indicate source positions: "stored" (safely stored within the shield pig), "Open" (partially extended), and "On" (fully extended in the source tube).
- Source switch assembly: A housing containing a microswitch, located at the extreme end of the source tube assembly, which functions to energize the "On" control light when the source is in the fully extended position.

Operation of the isotope camera is illustrated in Figure 26-5-4.

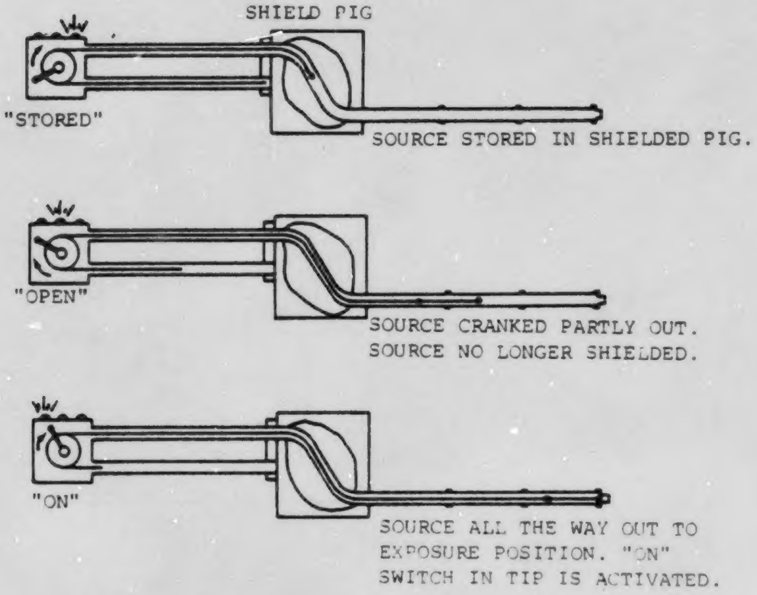

SHIELD PIG
"STORED"
SOURCE STORED IN SHIELDED PIG.
"OPEN"
SOURCE CRANKED PARTLY OUT.
SOURCE NO LONGER SHIELDED.
"ON"
SOURCE ALL THE WAY OUT TO
EXPOSURE POSITION. "ON"
SWITCH IN TIP IS ACTIVATED.

Figure 26-5-4. Camera Operation

The camera described operates with manual control, and may have a direct reading indicator of the length of cable extended to indicate source position. Cameras are also available with the same basic shield pig design, but with pneumatic or electrical drive units replacing the manual crank. Other types may also be obtained that do not require source removal from the pig, but permit exposure by the removal or re-orientation of a part of the source shielding.

X-Ray Sources

The basic requirements for the generation of X-rays are: a source of free electrons, a means of moving the electrons rapidly in the desired direction, and a suitable target material for the electrons. The X-ray tube supplies these requirement. In addition to the tube, an electrical power supply is required for supplying current to heat the tube filament for producing the electrons, and a high voltage source for accelerating the electrons toward the metal target. A basic X-ray tube is illustrated in Figure 26-5-5, "Diagram of an X-ray Tube".

The tube basically consists of two electrodes, the cathode and the anode, enclosed in a heavy, high vacuum envelope of heat resistant glass. A focusing cup surrounds the filament (cathode) to help direct the emitted electrons toward the target (anode). A dense target material with a high melting point, such as tungsten, is required to assure a maximum number of collisions while withstanding the high heat of X-ray generation. The area of the target struck by the stream of electrons is called the focal spot.

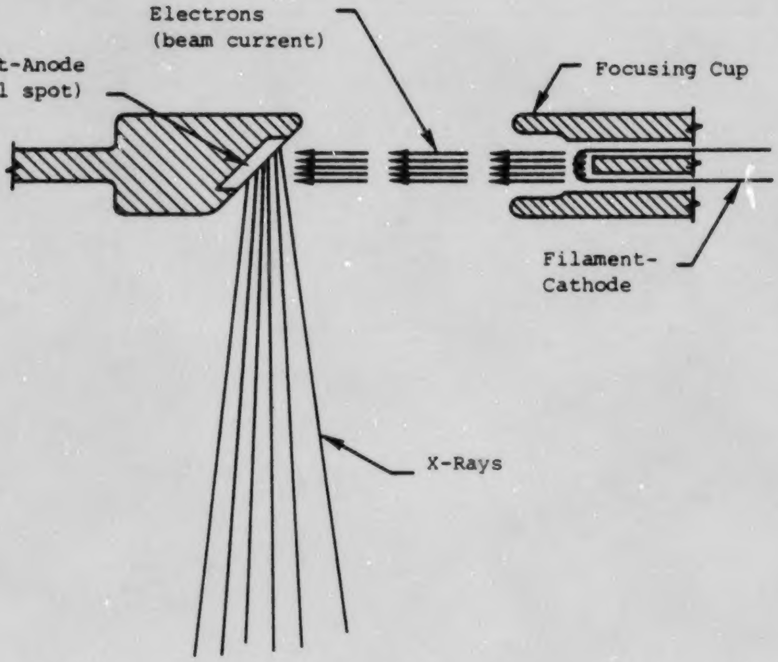

Electrons
(beam current)
Target-Anode
(focal spot)
Focusing Cup
Filament-
Cathode
X-Rays

Figure 26-5-5. Diagram of an X-Ray Tube

Filament power is furnished by a small low voltage transformer delivering a current of several amperes. A high voltage transformer provides voltage between the filament and the target. The higher the voltage, the greater the speed of the electrons to the target. High speed electrons produce X-rays of shorter wavelength and higher penetrating energy than do low speed electrons.

Most of the energy of the electron beam is expended in the production of heat. To avoid the destruction of the tube anode, the heat must be dissipated. Medium and low power tubes have a thermal conducting metal rod connected to the anode which conducts heat from the target to outside cooling fins. High power tubes have hollow anodes with a circulating water or oil system for heat removal. The duty cycle of the equipment (percentage of exposure time versus total time) is determined by the rate of anode cooling. The efficiency of the X-ray equipment is therefore limited by the efficiency of its cooling system.

X-ray tubes are rated by the voltage applied to the anode. Typical low-energy level X-ray machines may have tube voltages from 10,000 to 100,000 volts (10kV to 100kV). High energy machines may be rated at millions of volt. A characteristic of high-voltage radiography is that it is applicable to comparatively thick or highly absorbing specimens. X-ray machines designed for industrial applications have the approximate practical specimen thickness limits shown in Table 26-5-2:

TABLE 26-5-2. Industrial X-Ray Machine Applications

X-RAY KV	APPROX. PRACTICAL SPECIMEN THICKNESS LIMITS
50	Woods, plastics, thin light metals
100	2-inch Aluminum
150	1-inch Steel, 4½-inch Aluminum
250	2-inch Steel or Equivalent
400	3-inch Steel or Equivalent
1000	5-inch Steel or Equivalent
2000	9-inch Steel or Equivalent

X-ray intensity is not exactly proportional to tube current because the voltage and waveform of an X-ray machine transformer varies with the load.

Radiation from an X-ray tube may be considered to consist of two parts. These are referred to as the continuous X-ray spectra and the characteristic X-ray spectra. Electrons in the beam impinging on the target material and some electrons ejected from the target atoms give up kinetic energy as they strike nuclei of target atoms. The loss of energy results in X-rays. Since these electrons have a wide range of velocities, the X-rays generated cover a wide band of wavelengths. The wavelength depends upon the energy given up by the electron. This provides a continuous spectrum of X-rays and is the radiation most used industrial radiography. The characteristic X-rays are those resulting from the displacement of orbital electrons in the target material. This radiation is of a specific wavelength, "characteristic" of the element making up the target material, and of relatively small energy compared to that of the continuous spectrum.

Refresher on Radiation Detection and Measurement

Radiation coming from radioactive materials or X-ray producing equipment cannot be detected by man using only his senses. The body may be penetrated by intense radiation and severely damaged without feeling pain until some time later when radiation sickness develops or other biological effects are observed. Instruments must therefore be used to detect and measure radiation which poses such a threat.

The term detection refers only to the determination of the presence of radiation, whereas measurement includes both detection and quantitation of the radiation present.

Radiation measuring instrument usually provide a measurement of dose or a dose rate. The measurement of dose refers to the accumulated radiation exposure dose over a period of time, and dose rate refers to the immediate level of radiation intensity.

The Roentgen (R) is the unit of radiation exposure which is based on the ionizing effect of gamma or X-radiation passing through air. As applied in measuring occupational exposure, this is a rather large unit, so the milliroentgen (mR) is frequently used for measuring small doses (1R = 1,000 mR).

Dosimeters

Dosimeters are instruments which measure total dose exposure. Dosimeters are usually used by workers in areas exposed to radiation. The dosimeter indicates, at any time, the total radiation dose received to that time. Examples of dosimeters include:

- Lauritsen Electroscope

  This dosimeter consists basically of an ionization chamber for collecting the ions formed by penetrating radiation, with an insulated central electrode with one fixed and one movable part. Initially, the electrode is charged; the electrode parts, having the same electrical charge, are repulsed by a force proportional to the charge on the electrode, and the movable part (or quartz fiber) is deflected accordingly, a distance proportional to the charge on the electrode. As rays enter the chamber, ions of the opposite electrical charge are formed in the air, move toward and collide with the electrode, and neutralize an amount of charge on the electrode. As the radiation-ionization process continues, the electrode is discharged appreciably, and the change in position of the movable quartz fiber indicates along a linear scale graduated in Roentgen or milliroentgen units. When the unit is charged initially, the voltage is adjustable and sufficient to deflect the quartz fibre to coincide with the zero mark on the scale when viewed through the eye-piece. See Figure 26-5-6:

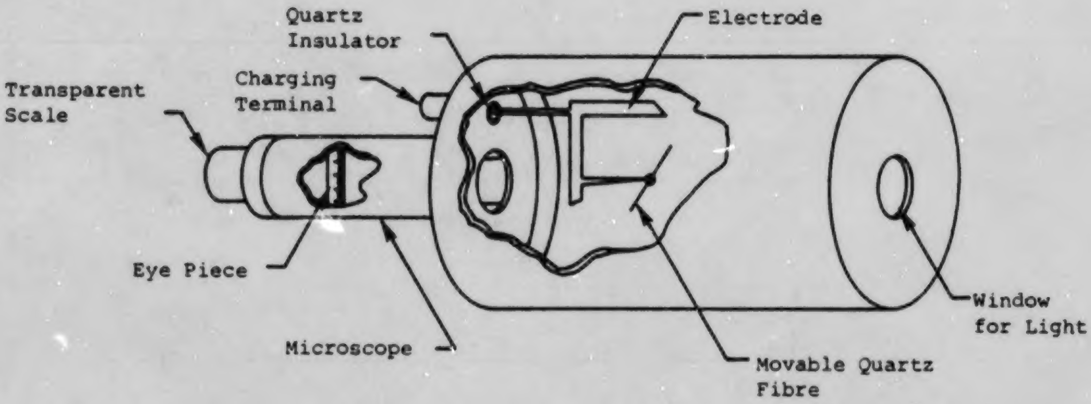

Quartz Insulator
Electrode
Transparent Scale
Charging Terminal
Eye Piece
Microscope
Window for Light
Movable Quartz Fibre

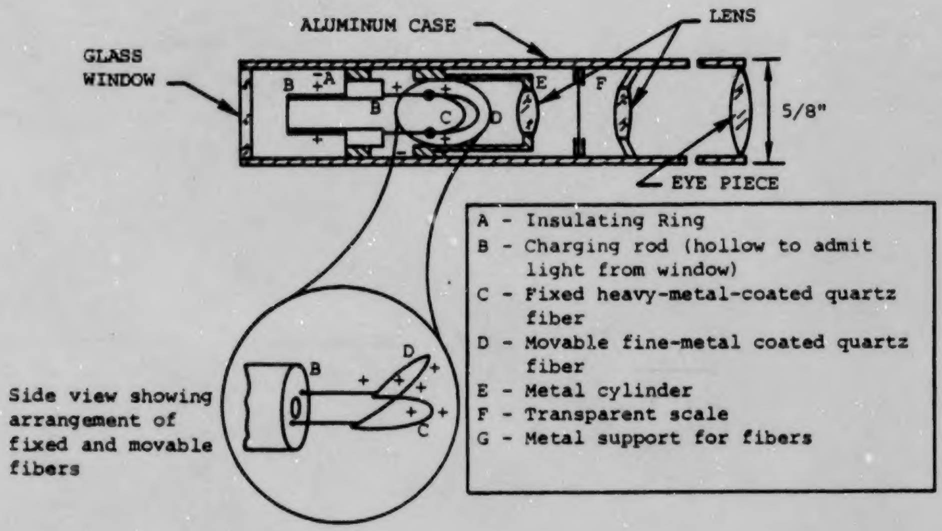
Figure 26-5-6. The Lauritsen Electroscope

- Self Reading Pocket Ionization Chamber (PIC) Dosimeter

The PIC dosimeter is also a quartz-fiber ionization chamber instrument, similar to the Lauritsen Electroscope, but of the compact size of a large fountain pen. The electrode consists of two U-shaped quartz fibers, one fixed and one movable. The fibers are fused together at the ends of the U, and a small microscope is focused on the opposite end of the movable fiber. A transparent scale appears in the lens system, with the most frequently used scale graduated 0-200 mR. See Figures 26-5-7 and 26-5-8.

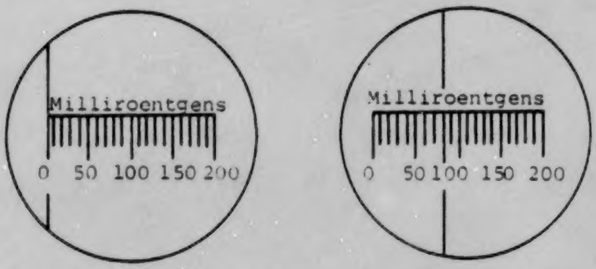
- Film Badges

Until recently, the film badge was usually the official record of whole-body radiation exposure. The film badge is a small plastic or metal holder designed to hold a photographic film packet similar to those used by dentists for X-raying teeth. The film packet contains two pieces of film, one relatively sensitive


ALUMINUM CASE
LENS
GLASS WINDOW
B
A
B
C
D
E
F
5/8"
EYE PIECE
Side view showing arrangement of fixed and movable fibers
B
D
C

A - Insulating Ring
B - Charging rod (hollow to admit light from window)
C - Fixed heavy-metal-coated quartz fiber
D - Movable fine-metal coated quartz fiber
E - Metal cylinder
F - Transparent scale
G - Metal support for fibers

Figure 26-5-7. Self-Reading Pocket Ionization Chamber (PIC)


Milliroentgens
0 50 100 150 200
Milliroentgens
0 50 100 150 200

Fully charged, "Zeroes" Condition.

Indication after exposure to 80mr ionizing radiation

Figure 26-5-8. Typical Pocket Dosimeter Scales

to radiation, covers a range of 10mR to 5,000 mR, and the other, relatively insensitive, covers a range of 400 mR to 600,000 mR. Ions produced by radiation in the film emulsion activate the silver molecules in the emulsion. When the film is developed, these activated silver atoms are reduced to elemental silver and turn black. A measurement of the "blackness", or density, of the film is a measure of the radiation dose received. The holder also includes small circles or squares of several metals (absorbers) to help determine the doses contributed by different energy groups of gamma radiation. The blackness of the film varies behind the different absorbers, because radiation of different energies will vary in penetrating ability through the respective absorbers. Evaluation of these areas on the film provides a more accurate determination of dose.

- Thermoluminescent Dosimeter - "TLD"

Most industrial users have replaced film badges with "TLD's" for providing an official record of whole body radiation exposure. Thermoluminescent is that property, of a previously excited material, to phosphoresce or give off light upon heating. Thermoluminescent materials, such as lithium fluoride or calcium fluoride are used in "TLD" badges; after exposure to radiation, the material gives off light when heated. The total quantity of light emitted is proportional to the amount of radiation which interacted with the material. TLD's have several advantages over film badges, such as greater stability, sensitivity and accuracy, and small size for use in measuring extremity exposures.

- X-ray Film

When using X-ray film for radiation monitoring, faster film is usually used for personnel monitoring and slower film is used for area monitoring.

Survey Meters

The instruments and devices described above all measure radiation exposure, but cannot be used effectively to make a rapid survey of an area. Instruments are needed to measure radiation intensity instantly; two such types of instruments are available - ionization chamber instruments with amplifier systems, and Geiger counters. Both types detect and measure gamma and X-radiation, and are used extensively for radiography work.

- Ionization Chamber Instruments

Instruments of this type measure high levels of radiation, usually up to 1,000 R/hour. Typical instruments have a meter with a scale reading from 1 to 1000, with a selector switch permitting reading mR/hour or R/hour.

The instrument operates in the following manner: When exposed to a radiation field, ionization occurs in a gas in an ionization chamber. The ions formed move to an electrode having the charge of opposite sign. The ions strike the electrodes, which are connected to an electrical source, are neutralized, and cause a small electrical current flow. The current flow is amplified, measured and interpreted in terms of the radiation intensity required to produce the ionization.

The accuracy of instruments of this type is plus or minus 15 percent, making them unsuitable for precision measurements, but they provide instantaneous measurement.

- Geiger-counters

Geiger-counters or Geiger-Mueller detectors are usually low level instruments and read only to about 50 mR/hour. They have a tendency to "block-out" in a high radiation field, and show only a small reading above zero due to background radiation. The user should be careful, therefore, in accepting a zero or near zero reading as meaning no radiation is present.

Geiger-counters derive their greater sensitivity from the "gas-amplification" characteristics of the Geiger tube itself, and their electronics amplifier circuits. In the Geiger tube, ions produced by penetrating radiation are attracted and move rapidly toward electrodes with a high voltage potential. These ions in motion strike other atoms with sufficient force to knock other electrons out ("inelastic collisions") and create other ions, thus increasing the total amount of ionization within the area. This phonomenon, known as "gas-amplification", produces a literal avalanche of ions for each photon or particle entering the chamber. With farther electronic amplification, each avalanche of ions may be indicated by the deflection of a meter needle and/or an audible "click".

The accuracy of instruments of this type is plus or minus 15%, making them unsuitable for precision measurements, but they are available as small, compact units and provide instantaneous measurement.

Instrument Calibration

Radiographers must be able to determine if the survey meters are operating properly and to check instrument calibration for correct readings (accuracy). Making such a check involves the following:

1) obtain a source of radiation, such as a radioisotope, for which the intensity is known.
2) place the survey meter at a distance computed to give a desired field intensity.
3) read the instrument to determine if the indicated reading is accurate.

This procedure and the required calculations will be discussed in greater detail later in this module under Geometric Principles and Applications.

Radiation Safety

Gamma and X-radiation are the primary radiation sources used in industrial radiography. Both can travel many feet through the air and penetrate deeply through human tissue, causing bioligical changes and damage in cell structure. Radiation safety practices are based on these characteristics and effects of radiation, and are designed to minimize exposure to personnel.

Radiation Dose Measurement

The damaging effects of radiation to living cells are dependent upon both the type and the energy of the radiation to which they are exposed. For this reason, exposure is first measured in physical terms; then, a factor to allow for the relative biological effectiveness of the different types and energies of radiation is applied.

The units used to measure radiation exposure are defined as follows:

- Roentgen: the unit for measuring penetrating external radiation, gamma or X-ray, in air only, which is abbreviated R. It can be subdivided into a smaller unit, the milliroentgen, abbreviated mR, which is 1/1000 of a roentgen.
- Rem: the term used to measure penetrating radiation in animal tissue or man. The rem (roentgen equivalent man) thus defines the biological effect of radiation on man, and is equivalent to the radiation absorbed dose (rad) multiplied by the relative biological effectiveness (rbe) of the radiation absorbed. The rem can be subdivided into the millirem, 1/1000 of a rem, and abbreviated mrem.
- Rad: the unit of measurement of radiation absorbed by humans. The rad (radiation absorbed dose) represents an absorption of 100 ergs of energy per gram of irradiated material, and applies to any type of radiation.
- Quality Factor (QF): the value of assigned to various types of radiation, based on the relative effect on the human body. QF values are shown in Table 26-5-3.

TABLE 26-5-3. Quality Factor (QF) Values

Radiation	QF
X-Ray	1
Gamma	1
Beta Particles	1
Thermal Neutrons	5
Fast Neutrons	10
Alpha Particles	20

In radiography work, gamma and X-radiation are of primary interest. Radiation safety levels are established in terms of rem dose. The calculating of rem dose is simplified by two facts: 1) the Roentgen dose is equivalent to the rad dose, and 2) the QF of both X- and gamma radiation is one. A measurement of Roentgen dose (or radiation intensity, with a survey meter) becomes a measurement of rem dose.

Control of Radiation Exposure of Personnel

Standards for protection against radiation hazards are outlined in the Code of Federal Regulations, Title 10, Part 20. The Code requires that users of radioactive materials "make every reasonable effort to maintain radiation exposure as low as in reasonably achievable," and prohibit individual radiation doses from exceeding the limits specified in Table 26-5-4.

TABLE 26-5-4. Radiation Dose Limits

Type of Exposure	Rems Dose, per calendar quarter
Whole body; head and trunk; active blood-forming organs; lens of eyes; or gonads	1 1/4
Hands and forearms; feet and ankles	18 3/4
Skin of whole body	7 1/2

Under certain conditions, the limit for whole body exposure may be increased to 3 rem in one calendar quarter. These limits are applied to the total amount of radiation received from radioactive materials, and other sources of radiation, such as X-ray equipment.

Protection Against Radiation

Three principles govern safety practices for controlling body exposure to radiation: time, distance and shielding. Safe radiographic installations and techniques are designed by applying these principles.

- Personnel exposure time: The amount of radiation absorbed by the human body is directly proportional to the time the body is exposed. A person standing in a radiation field of 120 [illegible]/hour would receive a dose of 2 mR each minute he remained at that location (e.g. 20 mR in/0 minutes, 40 mR. in 20 minutes, etc.) Work should be organized to spend the least possible time in any radiation field to minimize the dose received. See Figure 26-5-7.

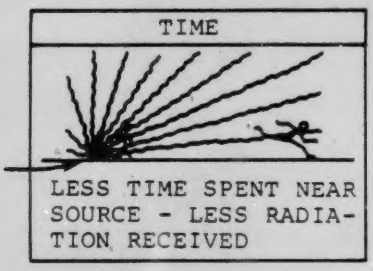

TIME
LESS TIME SPENT NEAR SOURCE - LESS RADIATION RECEIVED

Figure 26-5-7.

- Working Distance: Lower personnel exposures will be received at longer distances from radiation sources. The inverse square law is used to calculate radiation intensities at various distances from a source. The inverse square law is expressed as:

$\frac{I_1}{I_0} = \frac{D_0^2}{D_1^2}$ where I_1 and I_0 are radiation intensities at distances D_1 and D_0 respectively.

Table 26-5-5 lists dose rates of commonly used radioisotopes:

TABLE 26-5-5. Radioisotope Dose Rates

RADIOISOTOPE	DOSE RATE, R/HR/CURIE AT 1 FOOT
COBALT-60	14.5
IRIDIUM-192	5.9
CESIUM-137	4.2
THULIUM-170	0/03

The following examples illustrate methods used to calculate radiation intensities in terms of dose rate:

Example 1: Given a 10 Curie Cobalt-60 source, what is the emission or dose rate at 5 feet?

Step 1: From Table 26-5-6, the dose rate of Cobalt-60 is 14.5 R/hr/Ci at 1 foot. The dose rate of a 10 curie source at 1 foot is: 10 x 14.5 = 145 R/hr.

Step 2: I_0 = 145 R/hr

I_1 = ?

D_0 = 1 foot

D_1 = 5 feet

Step 3: Substituting in the inverse square equation,

$$\frac{I_1}{145} = \frac{1^2}{5^2} = \frac{1}{25}$$

Step 4: Solving for I_1 (intensity at 5 ft) -

$$I_1 = 145 \times \frac{1}{25} = \frac{145}{25} = \underline{5.8 \text{ R/hr.}}$$

Example 2: A 20 Curie source of Iridium-192 is used at a distance of 20 feet from a technician. What dose rate will be received?

Step 1: From Table 26-5-6, the dose rate of Iridium-192 is 4.9 R/hr/Ci at one foot. The dose rate of a 20 curie source at one foot is 20 x 5.9 = 118 R/hr.

Step 2: I_0 = 118 R/hr

D_0 = 1 foot

I_1 = ?

D_1 = 20 feet

Step 3: Substituting in the inverse square equation:

$$\frac{I_1}{118} = \frac{1^2}{20^2} = \frac{1}{400}$$

Step 4: Solving for I_1 (intensity at 20 ft) -

$$I_1 = 118 \times \frac{1}{400} = \frac{118}{400} = \underline{0.295 \text{ R/hr}} \text{ or}$$

295 mR/hr

Example 3: In example 2, at what distance from the source should the technician be to receive a dose rate of only 5 mR/hr?

Step 1: Dose rate at one foot, 118 R/hr or 118,000 mR/hr

Step 2: $I_0 = 118{,}000$ mR/hr

$D_0 = 1$ foot

$I_1 = 5$ mR/hr

$D_1 = ?$

Step 3: Substituting in the equation:

$$\frac{5}{118{,}000} = \frac{1^2}{D_1^{\,2}}$$

Step 4: Solving for D_1 (distance where intensity is 5 mR/hr):

$$D_1^{\,2} = \frac{1^2}{5} \times 118{,}000 = \frac{118{,}000}{5} = 23{,}600$$

$$D_1 = \sqrt{23{,}600} = \underline{153.6 \text{ feet}}$$

The same equation is applicable for calculating x-radiation intensities and distances, but it is first necessary to measure the intensity at a known distance from the X-ray source with predetermined ma and kv settings. Any change in X-ray machine settings will change the intensity, and a new intensity measurement would be required.

Personnel should remain as far from the source as possible at all times. See Figure 26-5-9.

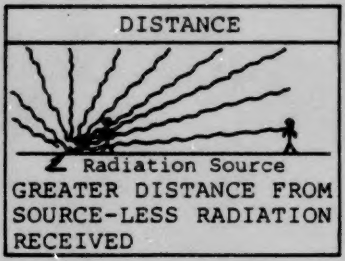

DISTANCE
Radiation Source
GREATER DISTANCE FROM SOURCE-LESS RADIATION RECEIVED

Figure 26-5-8

- Radiation Shielding: Some industrial situations require high intensity sources to be used frequently in confined areas. Having to work in close proximity to such a source, the radiographer may use shielding to minimize exposure to personnel. See Figure 26-5-9.

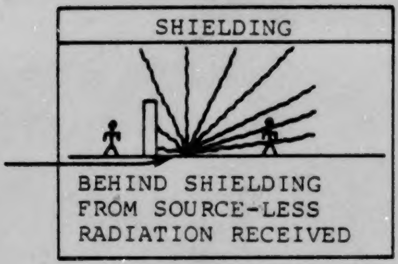

SHIELDING
BEHIND SHIELDING FROM SOURCE-LESS RADIATION RECEIVED

Figure 26-5-9

Gamma and X-rays are not wholly stopped, but are diminished in number by any given absorber. Materials having a high atomic number absorb more radiation than a material having a low atomic number. Lead, iron, concrete and water are commonly used shielding material.

The shielding efficiency of materials is measured in terms of half-value layers. The half-value layer is that amount of shielding which will stop half of the radiation of a given intensity. Tables 26-5-6 and 26-5-7 show the approximate half-value layers of shielding materials for gamma and X-rays respectively.

TABLE 26-5-6. Approximate Gamma Ray Half Value Layers

Shielding Material, In Inches	Half-Value Layer Thickness for Radioisotope Source		
	Cobalt-60	Iridium-192	Cesium-137
Lead	0.49	0.19	0.25
Steel	0.87	0.61	0.68
Concrete or Aluminum	2.6	1.9	2.1

TABLE 26-5-7. Approximate X-Ray Half Value Layers

Shielding Material	Half-Value Layers for X-Ray Tube Potential of:							
	50kV	70kV	100kV	125kV	150kV	200kV	250kV	300kV
Lead (mm)	0.05	0.18	0.24	0.27	0.3	0.5	0.8	1.3
Concrete (in)	0.2	0.5	0.7	0.8	0.9	1.0	1.1	1.2

The following examples illustrate the application of half-value layer information for reducing radiation intensities:

Example 1: In a previous example, a 20 Curie source of Iridium-192 was used at a distance of 20 feet from a technician, where the dose rate was 295 mR/hr. How much lead shielding would be required to reduce the radiation intensity to 10 mR/hr or less?

Step 1: Each half-value layer of lead placed between the technician and the source reduces the dose rate by 1/2. Thus,

1 Half-Value Layer (1/2 x 295 mR/hr) = 148 mR/hr
2 Half-Value Layer (1/2 x 148 mR/hr) = 74 mR/hr
3 Half-Value Layer (1/2 x 74 mR/hr) = 37 mR/hr
4 Half-Value Layer (1/2 x 37 mR/hr) = 19 mR/hr
5 Half-Value Layer (1/2 x 19 mR/hr) = <10 mR/hr

5 Half-Value Layers reduces the radiation intensity to less than 10 mR/hr.

Step 2: From Table 26-5-7, for Iridium-192, each half-value layer of lead is 0.19 in. thick. Five half-value layers of lead shielding are required, or 5 x 0.19 in. = 0.95 in.

Example 2: Radiation from a 300kV X-ray machine in an adjacent area is measured to be 200 times greater than the acceptable safe limit. How thick a concrete wall is required to reduce the radiation intensity to a safe level?

Step 1: Each half-value layer of concrete placed between the X-ray source and the subject area reduces the intensity by 1/2. Thus,

1 HVL = 1/2 original intensity
2 HVL = 1/2 x 1/2 = 1/4 original intensity
3 HVL = 1/2 x 1/4 = 1/8 original intensity
4 HVL = 1/2 x 1/8 = 1/16 original intensity

5 HVL = 1/2 x 1/16 = 1/32 original intensity
6 HVL = 1/2 x 1/32 = 1/64 original intensity
7 HVL = 1/2 x 1/64 = 1/128 original intensity
8 HVL = 1/2 x 1/128 = 1/256 original intensity
8 half-value layers will reduce the dose rate to a safe level.

Step 2: From Table 26-5-8, for X-ray tube voltage of 300-kV, the half-value layer thickness of concrete is 1/2 inches.
8 half-value layers are required, or
8 x 1.2 = 9.6 inches

Geometric Principles

General

A radiograph is a shadow picture of an object placed in a radiation beam. When an object is placed between a radiation source and a piece of film, a shadow of the object will be cast upon the film, producing a radiograph. See Figure 26-5-10. The image on the film must be developed chemically, of course, so that it can be viewed.

The relationships illustrated are caused by X- and gamma rays obeying the laws of light, except that materials are more or less transparent to the radiation. In passing through matter, however, some of the rays are absorbed. The amount of absorption at any point is dependent upon the thickness and density of the matter at that point, and procedures variation in the intensity of the emerging rays. This variation is detected and recorded on the radiographic film.

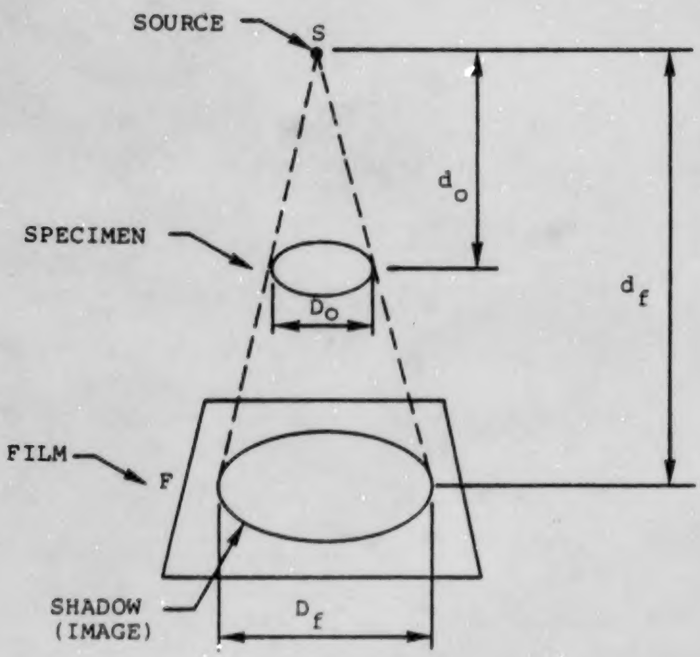


Figure 26-5-10. Shadow Formation

As illustrated in Figure 26-5-10, the enlargement of the image is caused by the film not being in contact with the specimen. If the object were lying on the film, there would be little or no enlargement. The ratio of the diameter of the object (D_o) to the diameter of the shadow (D_f) is equal to the ratio of the distance from the source to the object (d_o) to the distance from the source to the film (d_f), i.e., $\frac{D_o}{D_f} = \frac{d_o}{d_f}$.

Film Image Sharpness

Optimum geometrical sharpness of the image is obtained when the radiation source is small, the distance from the source to specimen is relatively large, and the distance from the object to the film is small. The geometrical unsharpness, or "penumbra", is illustrated in Figure 26-5-11.

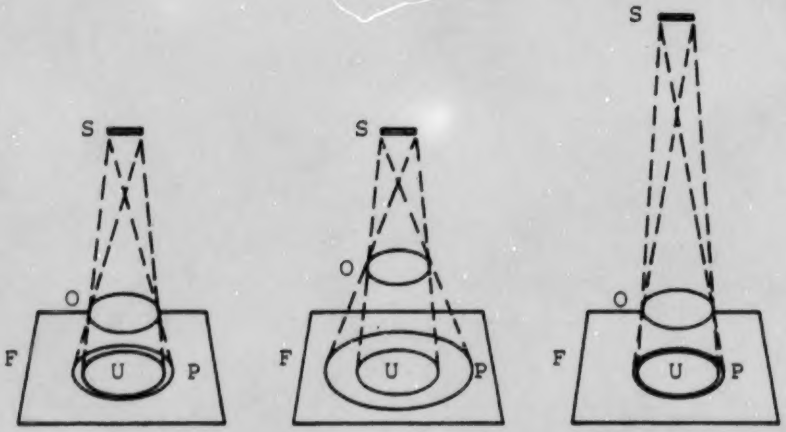


Diagram A Diagram B Diagram C

Figure 26-5-11. Geometrical Unsharpness, Penumbral Shadow

Legend:

S - Source
O - Object
F - Film
U - Umbra
P - Penumbra

Diagram A shows a small geometrical unsharpness (penumbra) when the specimen is close to the film.

Diagram B shows a greater geometrical unsharpness as the object is moved further from the film.

Diagram C, with the object-to-film distance the same as diagram A, shows the decrease in unsharpness as the source is moved further away from the object, increasing the source to film distance.

Film Image Distortion

Object images on film may be distorted as a result of:

- the plane of the specimen and the plane of the film are not parallel, and/or
- the radiation beam is not directed perpendicular to the plane of the film.

The resulting image distortions of the specimen also apply to the images of included discontinuities; this must be considered to avoid incorrect interpretation of the radiograph.

Film Image Enlargement

If the specimen is not in contact with the film some enlargement will take place, enlarging also any included discontinuities. In thick specimens, the images of discontinuities located away from the film side of the object will also be enlarged. Enlargement can cause misjudgement about the size of defects, but may also reveal small defects not noticeable on regular radiographs.

Summary

To produce an accurate representation of the specimen on the radiograph with a minimum of unsharpness, and distortion the following criteria should be observed:

- the radiation source should be as small as possible.
- the distance from the source to the film should be as large as practical.
- the film should be in contact with or as close to the specimen as possible.
- the center ray of the radiation beam should be perpendicular to the film
- the plane of maximum interest on the specimen should be parallel to the film.

Radiographic Film

Radiographic film consists of a thin, transparent plastic sheet coated on one or both sides with a radiation-sensitive emulsion of gelatin and silver bromide crystals. The silver bromide crystals react when exposed to X-, gamma or visible light radiation, are reduced to black metallic silver in the chemical developing process, and produce a dark gray image on the film. The film is viewed by using a bright light source (film viewer) and observing the image represented by high density (dark) areas and low density (light) areas.

The acceptability or usefulness of the resulting radiograph (e.g., whether the images of the specimen and discontinuities are identifiable) is dependent on adequate contrast and definition. Contrast is a comparison, or the difference in light transmission, between the high density areas and the low density areas, and definition if the relative sharpness of the image.

Radiographic Contrast

Radiographic contrast is a comparison of densitites on developed film, resulting from the following variables:

- Radiation source intensity (X-ray kilovoltage or gamma ray energy)
- Subject contrast

- Film density
- Screen usage
- Radiation scatter

These variables produce the effects listed:

- Radiation source intensity: generally, contrast is increased by lowering X-ray kilovoltage or by lowering the gamma ray MeV (e.g., substituting Ir-192 for Co-60 sources).
- Subject contrast: absorption of the radiation by the specimen is proportional to the thickness at any point (i.e., film exposure is greater at thinner areas of the specimen)
- Film characteristics: films are manufactured to produce different film contrasts and other properties.
- Film density or darkness is determined by exposure (radiation intensity X time), where increased exposure produces increased darkening, and by chemical processing, where increased development time produces increase darkening. Generally, film contrast increases as film density increases.
- Screen Usage: contrast may be increased with the use of fluorescent screens, which intensify the image, and with lead screens, which reduce back-scattered radiation and intensify the image.
- Radiation scatter: film fogging and loss of contrast may result from scattered radiation produced by rays deflected by the specimen, the film holder, the film, or the walls and floor.

Film Contrast and Denstiy, H & D Curve

Radiographic sensitivity is dependent upon the film contrast characteristics, or the ability of the film to detect and record different radiation exposures as differences in density. The relationship of film density to radiation exposure is described by the H & D curve, or characteristic curve for any particular film.

Exposure, E, of a film is defined as the product of the radiation intensity, I, reaching the film and the radiation exposure time, t.

$$E = I \times t$$

Since there are no convenient units, suitable to all X- and gamma radiation conditions, in which to express radiographic exposures, a relative exposure is used as one axis in plotting the H & D curve. Any exposure given a film is expressed in terms of any other exposure, producing a relative scale. For convenience, the logarithm, to the base 10, of the relative exposure itself is used, producing a compressed scale.

Film density, or more correctly called optical density, is plotted along the other axis on a linear scale and is defined mathematically as:

$$D = \log_{10} \frac{I_o}{I}$$

where: D = film density
I_o = intensity of light incident upon the film (or behind)
I = intensity of light transmitted through the film

The following example illustrates these concepts and the usefulness of the H & D curve:

1) A specimen with a thick section, A, and a thinner section, B, is radiographed: See Figure 26-5-12.

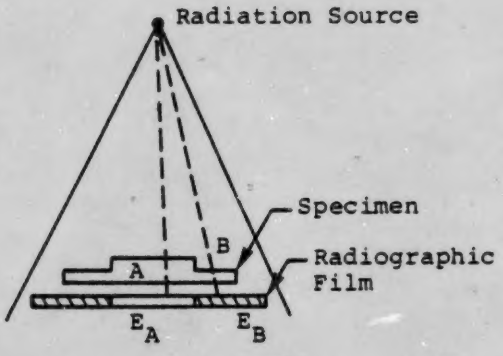


Figure 26-5-12. Producing the Radiograph

2) The exposed film, when developed, will have contrast between the area of low density, E_A, and the area of high density, E_B, See Figure 26-5-12.
3) When the developed radiograph is viewed on an illuminator, light will be transmitted in varying amounts through the film, as a result of the density differences, or contrast. See Figure 26-5-13:
4) The eye can readily interpret large density differences, or contrast, but there is a lower limit of contrast that cannot be detected by the naked eye. As the exposure and overall film density increases, the contrast increases; the H & D curve has a contour reflecting this relationship. (See Figure 26-5-14.

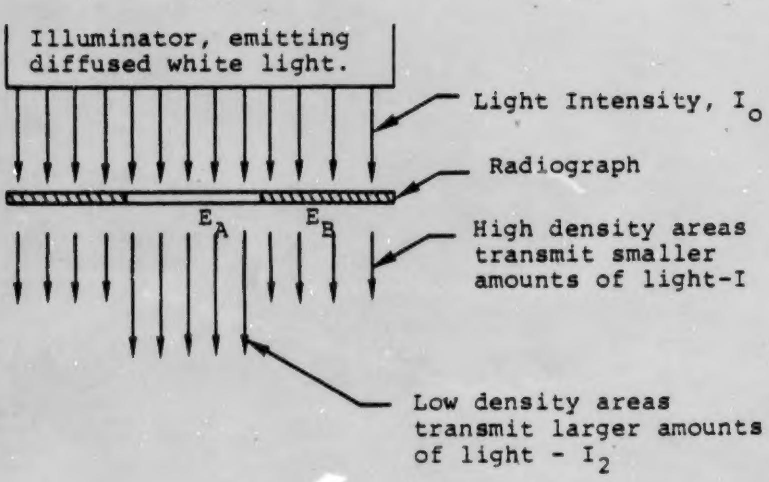

Illuminator, emitting diffused white light.
Light Intensity, I_o
Radiograph
E_A
E_B
High density areas transmit smaller amounts of light-I
Low density areas transmit larger amounts of light - I_2

Figure 26-5-13. Film Density

In the case of the radiograph illustrated in Figures 26-5-12 and 26-5-13, it can be seen that the film exposure E_A at radiation path A is less than the exposure E_B at radiation path B. For a low exposure at E_1, the result is that film density dA_1 is less than film density dB_1. The difference in denstiy, $dD_1 = dB_1 - dA_1$, is film contrast. In the low density portion of the H & D curve, i.e., density less than 1.0, the low contrast dD_1 will probably not be discernible by the eye.

By increasing the exposure to the value represented by E_2, the overall density of the radiograph is increased and the contrast or density difference between E_A and E_B (i.e., dA_2 and dB_2) is greatly increased. The resulting contrast is easily detectable by the eye. In this manner, the film's contrast characteristics may be used to select the exposure which will amplify the subject contrast. It may be stated that curve is a measure of film contrast.

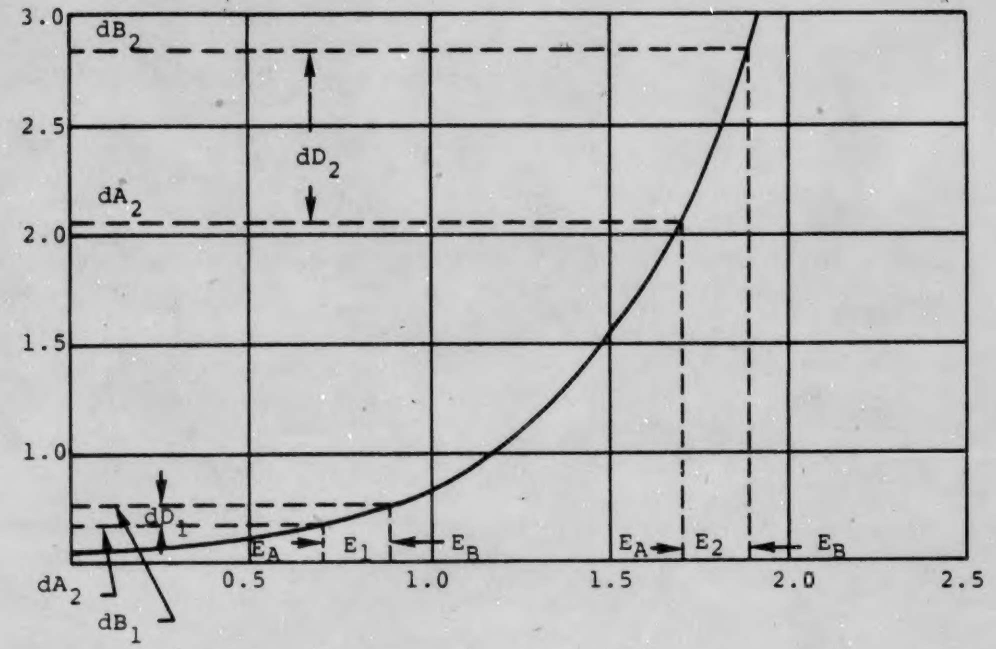


Figure 26-5-14. Film Characteristic Curve, "H & D" Curve

The H & D curves for films are also influenced by the film speed or film sensitivity. Film speed is the relative exposure required to obtain a desired film density. Generally, a high-speed (fast) film requires a low exposure, while a slow-speed film requires more exposure to reach the same density.

Film speed of films, Figure 26-5-15, is indicated by the position of H & D curves along the log E axis. Faster films are located toward the left, and slower ones to the right.

In industrial radiography, films should be exposed to produce maximum radiographic contrast. It can be seen from the H & D curves shown in Figure 26-5-15, that the slopes

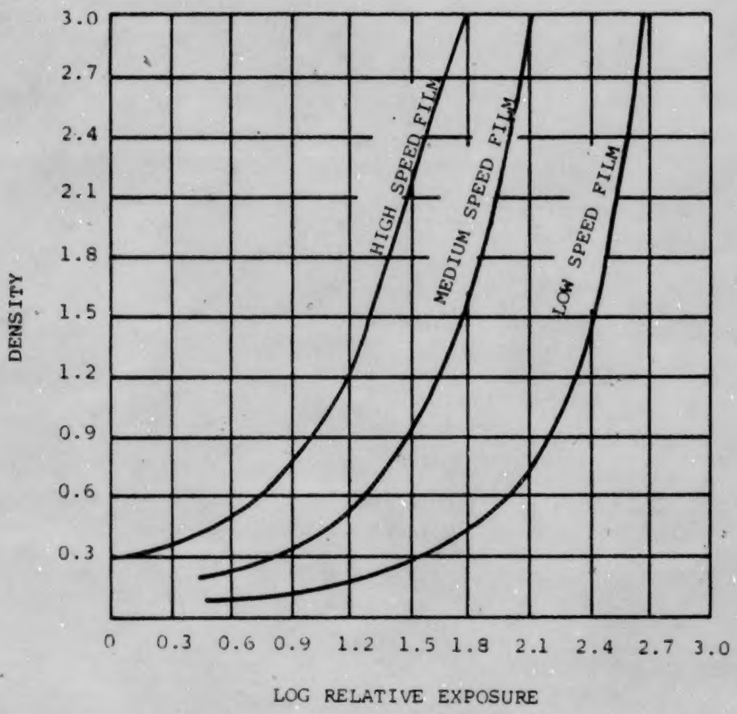


Figure 26-5-15. Relative Film Speed

of the curves are the steepest above a density of 1.5, and in most areas, film should be exposed to obtain a minimum density of 1.5, thereby optimizing film contrast characteristics.

If is known that the density of a film increases with increasing exposure up to a maximum value. Increasing the exposure beyond this point results in an actual decrease of density. This phenomenon is referred to as reversal.

Film Graininess

Graininess is the grouping or clumping of minute silver particles that form the image or radiographic film. This characteristic determines the fineness of detail that can be perceived on a film. Generally, fast films have large grain and poor resolution characteristics, while slow films have fine grain and good resolution.

Film Selection

The radiograph must have acceptable quality to resolve the specimen discontinuities which are likely to affect the specimen in service. Film contrast, speed, and graininess are interrelated, so the proper film must be specified to provide the desired contrast, image sharpness, and minimum exposure time. Films of various characteristics are available for many specific purposes and may be selected to meet these criteria.

Film Processing

Once a radiographic exposure has been made, the film must be processed chemically to convert the latest image into a visible one. The process includes five distinct steps, Developing, Stop Bath, Fixation, Washing, and Drying, which are described as follows:

- Developing: The chemical reaction involved in reducing the silver bromide crystals in the film emulsion to metallic silver.

  Commercially prepared developers are usually used, which are obtained in powder or liquid form and dissolved in or diluted with water.

  The developing process begins when the film is put into the developer solution. The amount of silver bromide changed is a function of time and the chemical solution strength and temperature. The density of the radiographic image is proportional to the length of time the film remains in the solution up to a limit, beyond which chemical fogging may occur with a decrease in contrast. Normal developing time for industrial radiographic films is usually 5 to 8 minutes to obtain optimum density and contrast.

The developing process is also temperature-sensitive. Normally, solution temperatures are maintained at 68°F (20°C). Lower temperatures will retard the action of the chemicals sufficiently to produce underdevelopment, and excessively high temperatures can fog the film or soften and damage the emulsion.

In addition to time and temperature control, agitation of the film in the developer is necessary for development uniformity. Shaking the film holders for a few seconds every minute of development time usually produces satisfactory results.

Replenishment or replacement of the developer solution is also required as the solution becomes weaker through use. Exhaustion of the developing agent occurs as silver bromide is converted to metallic silver, and the reaction products accumulate in the solution. If replenisher is used, the developer should be discarded when the quantity of the replenisher added equals 2 to 3 times the original quantity of the developer.

- Stop Bath: A mild acetic acid solution used to arrest film development.

  The stop bath solution is used to remove the residual developer from the film, stop the development action, and prevent uneven development and film streaking. It also serves to neutralize the alkali retained in the emulsion, permitting the acid in the fixer solution to function effectively. The proper stopping procedure is to:

1) remove film from the developer and allow to drain for a few seconds
2) immerse film in stop bath for 30-60 seconds with moderate agitation
3) remove film for transfer to the fixer solution

The stop bath solution should be maintained at the same temperature as the developer, and replaced when exhausted. When fresh, the solution is yellow in color; when spent, the color changes to a blue-purple.

- Fixation: The use of an acidic solution which removes the unexposed silver bromide crystals remaining in the fiber emulsion.

If not removed, the remaining crystals will darken when exposed to light and ruin the radiograph.

The fixer solution also hardens the gelatin on the film so that it will withstand drying with warm air.

Films should be agitated vigorously when placed in the fixer, then at two minute intervals. Fixing time should be approximately twice the time it takes to clear the undeveloped silver halide from the film (clearing time), or from about 8 to 15 minutes, depending on the solution age or usage.

The temperature of the bath should be maintained between 65°F and 70°F. To maintain the solution activity, replenisher may be added twice, in accordance with the manufacturer's instruction, before the solution is discarded and replaced.

- Washing: The thorough flushing of developed and fixed film to remove the residual fixer.

  Films should be rinsed in running water of 65°F to 70°F temperature for 20 to 30 minutes, making sure that the entire emulsion area is exposed to frequent water changes or an hourly flow rate of 4 to 8 times the tank volume.

  When film is removed from the wash tank, small drops of water cling to the emulsion, which can cause spotting and streaking on the finished film. The film may be immersed in a wetting agent solution for one or two minutes to cause the water to drain off more evenly and prevent or reduce such damage.

- Drying: The final step of film processing, usually accomplished by hanging the film in a drying cabinet, or in an area where dry air circulates freely to uniformly dry both sides of the film simultaneously.

The entire film processing cycle is shown in Figure 26-5-16.

Film Processing Facilities

All radiography operations must have film processing facilities; either automatic processing or manual processing equipment may be used.

An automatic processing machine is a complete integrated system which accomplishes all required processing steps from development through rinsing and drying. The only manual operations necessary are the loading and unloading of the film. The entire processing cycle is completed in less than 15 minutes through the use of special chemicals, continual agitation of the film, elevated chemical temperatures, and

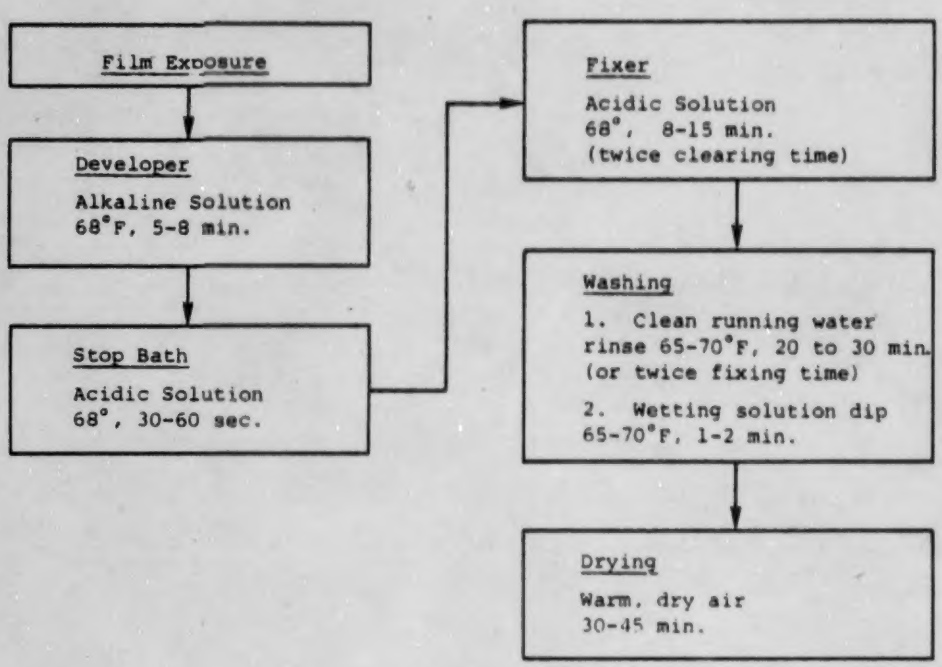

Film Exposure
Developer
Alkaline Solution
68°F, 5-8 min.
Stop Bath
Acidic Solution
68°, 30-60 sec.
Fixer
Acidic Solution
68°, 8-15 min.
(twice clearing time)
Washing
1. Clean running water rinse 65-70°F, 20 to 30 min.
(or twice fixing time)
2. Wetting solution dip 65-70°F, 1-2 min.
Drying
Warm, dry air
30-45 min.

Figure 26-5-16. Film Processing Cycle

drying with jets of heated air. Automatic processors, when properly operated and maintained, consistently produce radiographs of higher quality than those processed manually.

Manual film processing operations must be performed in a darkroom under appropriate safelight conditions. The location, design and construction of the facility depends on the volume of processing work to be done. The basic equipment components needed are: loading bench for handling film, film storage cabinets, chemical processing tanks and film dryer. For high quality results in manual film processing, the following factors must be implemented:

- darkroom areas shall be lighted with safelights of sufficient intensity for processing operations without endangering film by exposure to light.
- darkroom must be protected against light from outside sources.
- "wet" and "dry" areas must be separated to preclude film damage from water and chemicals.
- a high degree of cleanliness must be maintained in all areas to prevent contamination from dust, dirt and chemicals.

Radiographic Accessory Equipment

Screens

Radiographic screens are used to intensity the photographic action of radiation on the film, and to improve the image by absorbing scattered radiation.

Lead foil screens, usually from 0.004 to 0.006 inches thick, are normally used on both sides of the film in industrial radiography to improve the radiographic quality. The intensifying action of the lead foil screen is caused by the electrons emitted under gamma or X-ray excitation. Lead screens are used for almost all exposures when using high-voltage radiography.

Fluorescent screens have the ability to absorb gamma and X-rays and emit light (fluoresce). Film may be clamped between a pair of these screens during exposure, thereby intensifying the image. This technique may produce excessive graininess, however, and is seldom used in high-energy industrial radiography.

Filters

Filters are generally used in X-ray radiography, between the radiation source and the specimen, to absorb scattered radiation. Filters are usually made from metals with a high atomic number, such as lead, steel or copper, and absorb more of the "soft" or low intensity X-rays than the "hard" or high intensity X-rays. They are useful in minimizing overexposure of thin areas of the specimen, and reducing undercut near the edges of the specimen. Experience has shown that in the radiography of steel specimens, a lead filter of about 3% or a copper filter of about 20% of the maximum steel thickness gives good results.

Masks and Shields

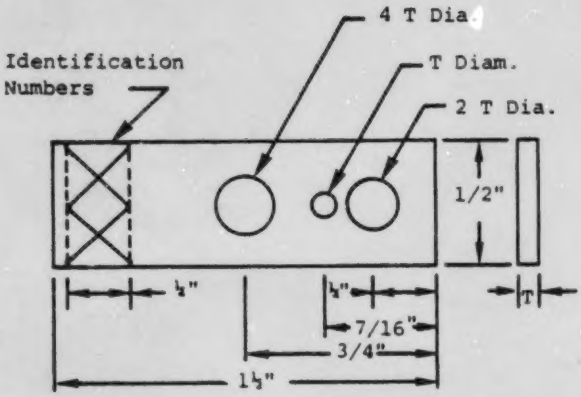
Radiation scatter reaching the film may also be minimized with the effective use of masks and shields of lead, barium clay, metallic shot or other absorbent material placed around portions of the specimen or areas surrounding the specimen. Masks absorb the soft rays and many of the higher energy rays, and shields limit scatter by absorbing rays that strike walls, floors and other objects that would generate scattered radiation.

Penetrameters

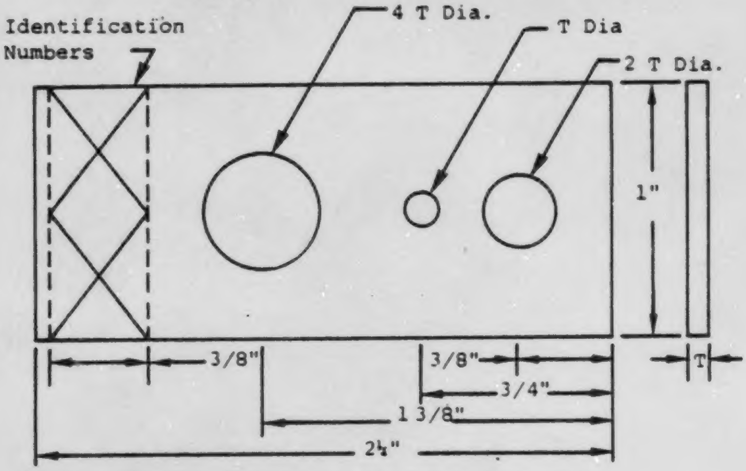
A penetrameter is a device whose image on a radiograph indicates the quality and sensitivty of the radiograph. The standard penetrameter is a small rectangular strip of material, radiographically similar to the material being radiographed, with 2 drilled holes of set diameter. The penetrameter is identified by a lead number (ID No.) which indicates the maximum thickness of the material for which the penetrameter is normally used.

The thickness of the penetrameter is determined by the required sensitivity of the radiograph. Percent sensitivity is the smallest detectable thickness of the material being examined, expressed as a percentage. The value of 2 percent has been arbitrarily set and is generally accepted for most routine radiographic work. When a penetrameter with a thickness of 2 percent of the specimen thickness is selected for use, therefore, the radiographic sensitivity is said to be 2 percent.

If the construction of nuclear power plants, welding work is conducted in accordance with the requirements of the ASME (American Society of Mechanical Engineers) Boiler and Pressure Vessel Code. Included in this Code are requirements for the radiographic examination of welds, and descriptions of the penetrameters to be used as a check on the radiographic technique. The ASME Code requires a radiographic sensitivity of 2 percent, and a penetrameter thickness of not more than two percent of the thickness of the specimen. The ASTM (American Society for Testing and Materials) type penetrameter, as shown in Figure 26-5-17, is used for ASME work applications, and has provisions for different quality levels of inspection. Each penetrameter contains three (3) drilled holes having diameters of 4, 1 and 2 times the penetrameter thickness (T), with minimum holes sizes of 0.040", 0.010" and 0.020" respectively. The quality levels are established for the penetrameters based on the visibility of the holes on the radiograph. For example, a quality level may be designated as "2-2T", where the first digit indicates a penetrameter thickness of 2% of the specimen thickness, and the "-2T" indicates the hole which must be visible on the radiograph. The Quality Level data is listed in Table 26-5-8.


4 T Dia.
Identification Numbers
T Diam.
2 T Dia.
1/2"
¼"
¼"
7/16"
3/4"
1¼"
T

Penetrameter Design for Thickness from 0.005" to 0.050"
From 0.005" through 0.020" Made in 0.0025" Increments.
From 0.025" through 0.050" Made in 0.005" Increments.


Identification Numbers
4 T Dia.
T Dia
2 T Dia.
1"
3/8"
3/8"
3/4"
1 3/8"
2¼"
T

Penetrameter Design for Thickness from 0.060" to 0.160"
Made in 0.010" Increments

Figure 26-5-17. ASTM Penetrameters

Designated Quality Level of Inspection	Penetrameter Thickness	Perceptible Hole Dia.	Equivalent Penetrameter Sensitivity
1-1T	1% of Specimen	1T	0.7%
1-2T	1% of Specimen	2T	1.0%
2-1T	2% of Specimen	1T	1.4%
2-2T	2% of Specimen	2T	2.0%
2-4T	2% of Specimen	4T	2.8%
4-4T	4% of Specimen	4T	4.0%

Table 26-5-8. Quality Levels of Inspection

Film Identification and Orientation

Appropriate marking on the specimen and the radiograph must be provided to permit correct radiographic interpretation. Lead numbers and letters are usually placed on or adjacent to the specimen, during the exposure, attached with masking tape, and appear on the finished radiograph. The specimen is then marked in identical fashion with a pen or scriber to preclude improper identification or orientation.

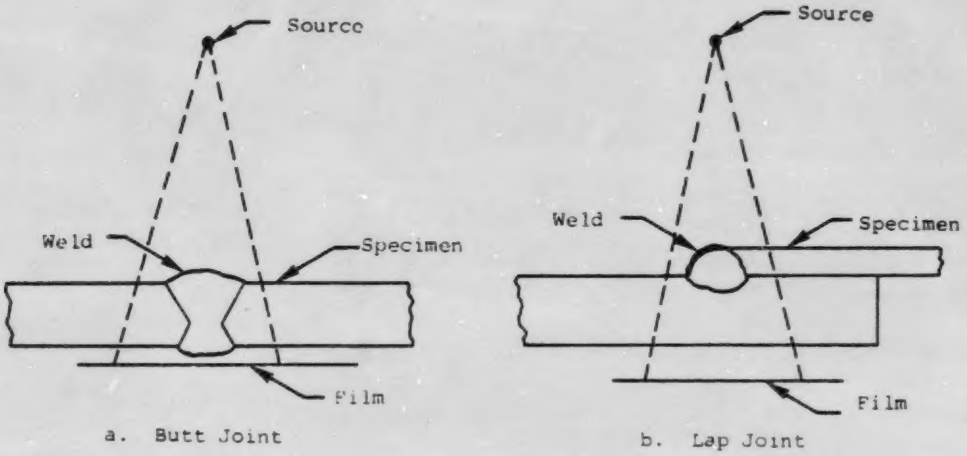
Applicability of Radiographic Techniques

Radiography is very useful in examining a variety of products, ranging from welding and metal castings, to nonmetallic materials such as plastics and ceramics. Regardless of the type of material to be examined, the same basic principles of film density and contrast apply, which are controlled by source-to-film distance, source orientation, source energy, exposure and film type.

For optimum radiographic results, the following factors must be considered for the test arrangement:

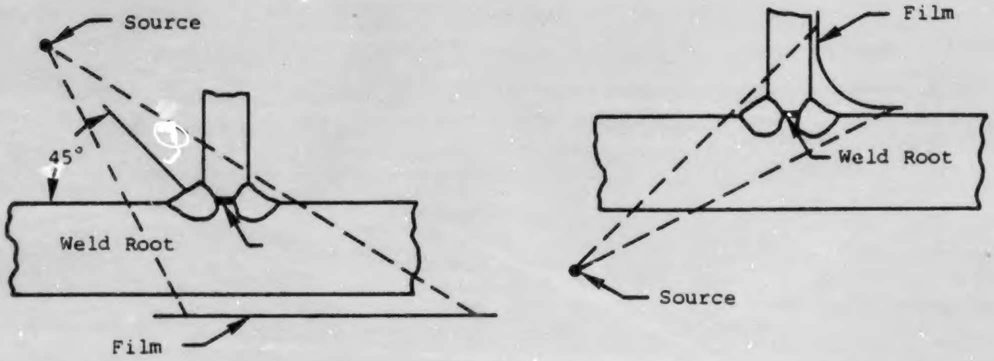
- producing best radiographic contrast of that area of the specimen most likely to contain discontinuities
- minimizing exposure time.
- minimizing distortion of the specimen in the area of interest.
- minimizing the number of exposures and films required.

The following sketches illustrate various applications of exposure arrangements:


Source
Weld
Specimen
Film
Source
Weld
Specimen
Film

a. Butt Joint b. Lap Joint

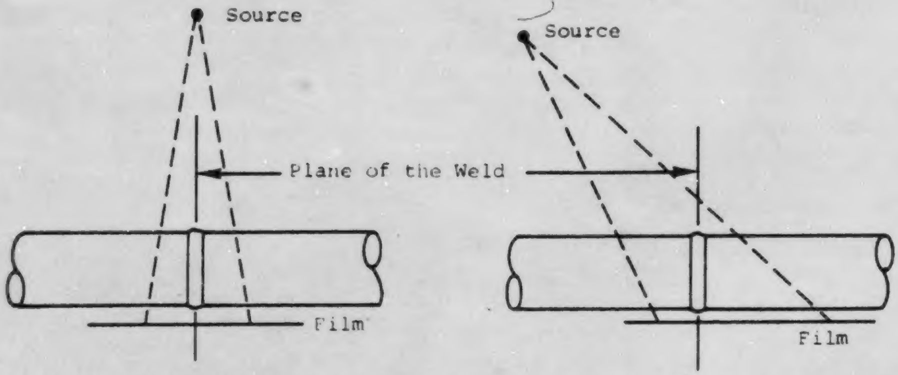
Figure 26-5-18. Flat Welded Plates


Source
45°
Weld Root
Film
Film
Weld Root
Source

a. Source on Welded Side of Base Plate

b. Source on Opposite Side of Base Plate from Welds

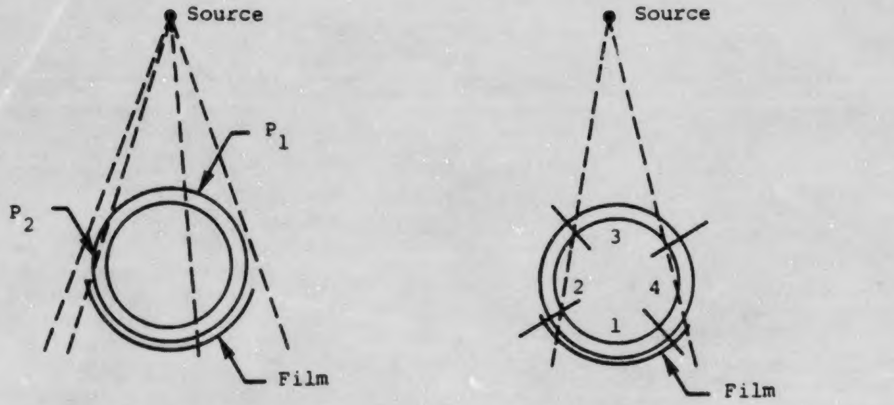
Figure 26-5-19. Welded "T" Joints on Plate


Source
Source
Plane of the Weld
Film
Film

a. Source In-line with Circumferential Weld Axis

b. Source Off-set from Circumferential Weld Axis

Figure 26-5-20. Small Pipe Welds


Source
P_1
P_2
Film
Source
3
2
4
1
Film

a. Specimen Variable Density

b. Specimen Multiple Exposures

Figure 26-2-21. Large Pipe Welds

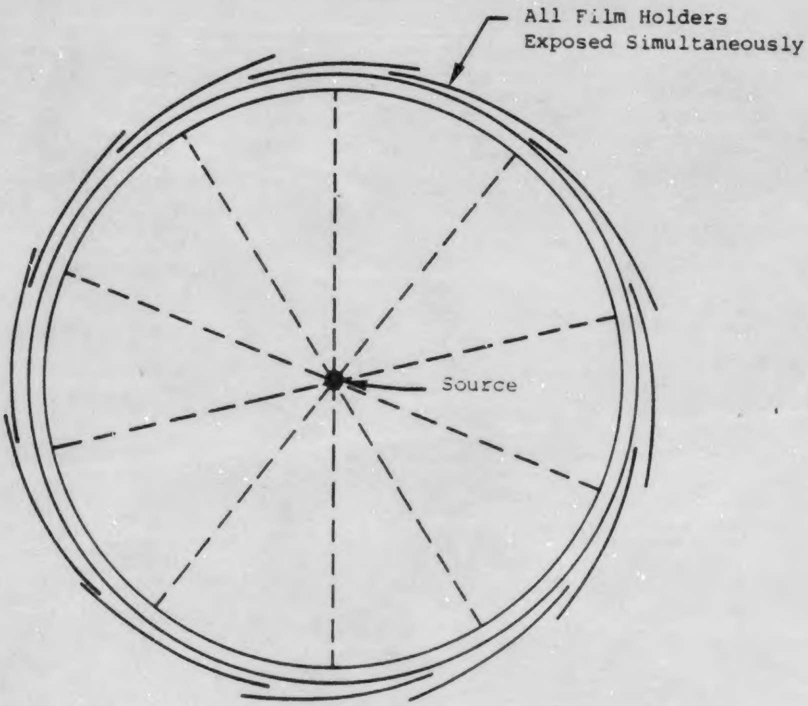

All Film Holders
Exposed Simultaneously
Source

Figure 26-5-22. Panoramic Exposure, Large Pipe or Pressure Vessel

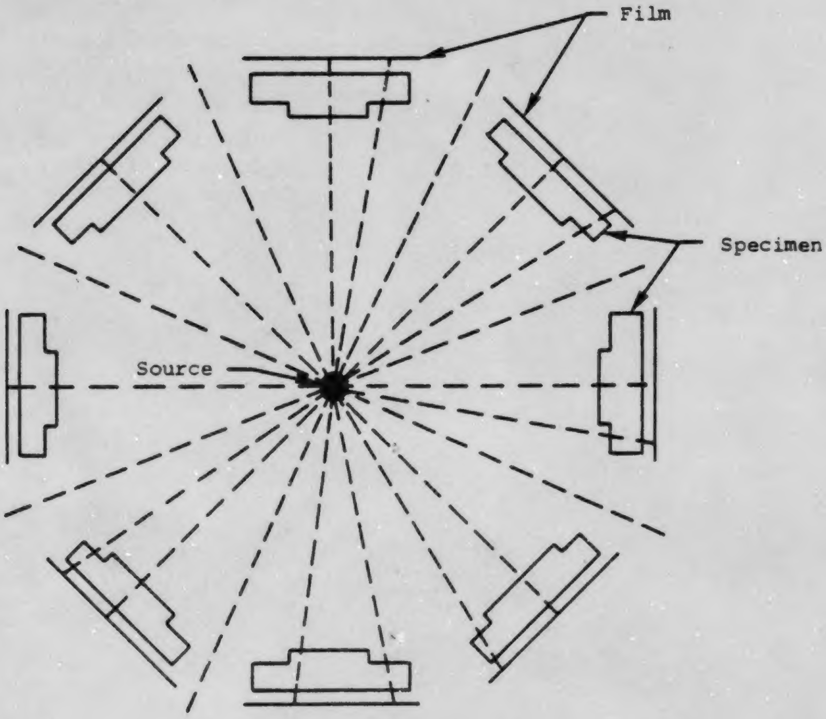


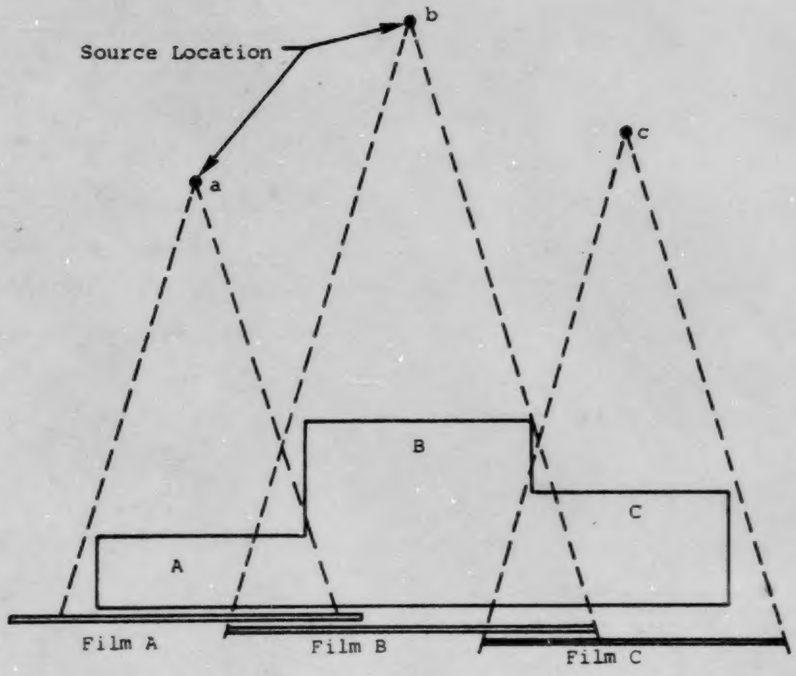
Figure 26-5-23. Panoramic Exposure, Multi-Specimen

Advantages and Disadvantages of Radiographic Techniques

The radiographer must consider and evaluate all factors, including the advantages and disadvantages of appropriate techniques, in selecting optimum test arrangements. The techniques previously illustrated are typical of those used in industrial radiography, and are discussed as follows:

- Figure 26-5-18, Flat Welded Plates

  One of the simplest subjects to radiograph is the welded butt joint. Subject contrast is minimal, the critical area is well defined.



(Specimen with Wide Range of Subject Contrast)

Figure 26-5-24. Multiple Exposure

The lap joint is also a simple arrangement, but the exposure must be made to produce the proper film density on the thicker part of the specimen.

- Figure 26-5-19, Welded "T" Joints or Plate

In the welded "T" joints, discontinuities are generally found in the weld root area. No location can be found, however, for placing the film to obtain good image resolution. Distortion may be minimized by using a long source-to-film distance, but at the expense of greatly increased exposure time.

- Figure 26-5-20, Small Pipe Welds

  In radiographing welds on small pipe (1 1/2" or less), the entire weld can be shown on one film. As shown in the first illustration (a), however, it would not be possible to determine whether a defect were present in the near wall or the far wall (relative to the source) due to the superimposed image. The offset arrangement (b) is preferred, because the weld image is cast upon the film as an ellipse, showing all areas of the weld and any included discontinuities. Defects occurring in the wall nearest the source will not be in sharp focus and have clear definition, however, unless the source-to-film distance is large.

- Figure 26-5-21, Large Pipe Welds

  The length of the radiation path through large pipe is difficult to measure and presents a problem of variable density in the specimen, which prohibits shooting the entire weld on one film. (The total length of radiation path P_1 in the pipe material is much shorter than the length at path P_2, as shown in sketch a.) It is preferred to divide the circumferential weld into 3 or 4 segments and radiograph each with a separate exposure, as indicated in sketch b.

- Figure 26-5-22, Panoramic Exposure, Large Pipe or Pressure Vessel

  If the pipe is large enough, generally 12" or greater in diameter, and its interior is accessible, entire circumferential welds may be radiographed with one exposure, with the film placed on the exterior of the pipe as shown in Figure 8.5. Pressure vessels may be radiographed in the same manner. This technique produces quality radiographs of uniform density in a fraction of the time required to make separate exposures of each area or segment.

- Figure 26-5-23, Panoramic Exposure, Multi-Specimen

  This figure illustrates a technique for radiographing a number of similar specimens, in similar position, with one exposure of the source placed at the geometric center of the arrangement. Much of the set-up time and exposure time required for individual exposures is saved as well as minimizing the radiation exposure hazard to the radiographs.
- Figure 26-5-24, Multiple Exposure

  Specimens with a wide range of subject contrast cannot be radiographed with one exposure, and achieve acceptable radiographic density in all areas. Separate source locations and exposures may be required as shown in this figure. In examining area A of the specimen, for example, Film A would be placed, and the source located at "a". The exposure would be made, Film A removed, and a similar set-up made to examine area B, with the procedure then repeated for area C. This technique provides high resolution of discontinuities throughout the specimen, at the expense of the additional time required for the set-ups and exposures.

EXERCISES

The following exercises serve to reinforce the concepts presented in this module.

1. Define or briefly explain the following terms:
   (a) particulate and electromagnetic radiation
   (b) gamma radiation sources
   (c) X-ray sources

(d) radioisotope source and capsule characteristics
(e) radioisotope cameras and accessories
(f) X-ray machine characteristics
(g) radiation detection and measurement equipment
(h) equipment calibration

2. Explain the principles of radiation safety as related to time, distance, and shielding, and define the following terms: Roentgen, rem, and rad.

3. Given a 4 Curie Cobalt-60 source, calculate the gamma-ray dose rate at:
   (a) four (4) feet
   (b) eight (8) feet

4. A 20 Curie source of Iridium-192 is used at a distance of 20 feet from a technician where the dose rate is measured at 295 mR/hr. Calculate the amount of lead shielding required if the technician is to work 8 feet from the source and to be in a radiation field of less than 10 mR/hr.

5. Given information such as radioisotope or X-ray dose rate and shielding values, calculate:
   - emission or dose rate at a given distance
   - dose rates at different distances
   - half-value layers of shielding required to meet radiation intensity requirements at specific distances

6. Explain geometrical unsharpness as related to the location of the source specimen and film.

7. Define or briefly explain the following terms:
   - (a) film contrast
   - (b) subject contrast
   - (c) film density
   - (d) H & D curve
   - (e) film speed
   - (f) film graininess

8. Demonstrate a knowledge of the operation and usage of radiation detection and measurement equipment by pointing out and identifying on illustrations or actual devices the various controls, and explaining the method of operation and usage in actual practice. This should be carried out following Procedure #1 given in this module.

9. Demonstrate a knowledge of the operation and usage of x-ray equipment and photographic emulsions employed in radiography as outlined in Procedure #2 given in this module.

10. Visit a welding shop in your area employing radiographic testing of the completed welds. Using Procedure #3 study selected specimens that are to be radiographed and follow the procedure to ensure that the radiographic non-destructive examination test has been set up properly.

MATERIALS

These materials are suggested in reference to carrying out Exercises #8, #9, and #10 of this module. These should be available at the site(s) visited.

1. For Exercise #8 - Laboratory visit where radiation detection equipment is employed.
    a. Pocket Dosimeter
    b. Film Badge
    c. Thermoluminescent Dosimeter (TLD)
    d. Ionization Chamber
    e. Geiger-Mueller Detector

2. For Exercise #9 - Dental x-ray laboratory visit.
    a. Geiger-Mueller Detector
    b. Ionization Chamber
    c. Film badge or TLD
    d. Photographic emulsions to produce radiographics
    e. Photographic developing equipment

3. For Exercise #10 - Welding shop visit to observe radiographic testing.
    a. Specimens to be radiographed
    b. Geiger-Mueller Detector
    c. RT test procedure
    d. Radioisotope or x-ray source
    d. Radioisotope camera and accessories
    f. Photographic emulsions for RT examination
    g. Photographic development equipment

PROCEDURES

The following procedures relate to Exercises #8, #9, and #10 of this module.

1. Procedure #1 - (In reference to Exercise #8)
    a. Visit a laboratory in your area which uses radiation detection and measurement equipment. These would typically be:
        (1) Hospitals employing nuclear medicine
        (2) Nuclear power station
        (3) Radioisotopes laboratory
        (4) Government research reactor facility

    b. Examine the following types of detectors:
        (1) Pocket dosimeter
        (2) Film badge
        (3) Thermoluminescent dosimeter (TLD)
        (4) Geiger-Mueller Detector
        (5) Ionization chamber

    c. Use the ionization chamber and the Geiger-Mueller detector to make radiation survey measurements using either an x-ray or gamma-ray source.

    d. Prepare a report on your visit which includes the data requested in Table 26-5-9 in the Data Table section of this module.

2. Procedure #2 - (In reference to Exercise #9)
    a. Visit a dental office in your area which uses x-ray equipment.

    b. Discuss the operation of this equipment with the laboratory technician.

c. Examine the operating procedures for the use of the x-ray machine.

d. Examine any "fail-safe" safety or warning devices incorporated into its design.

e. Examine the x-ray tube (or source) housing and its construction.

f. Examine the generator cabinet for the x-ray machine and any protective or warning devices associated with the cabinet.

g. With the assistance of the technician, take an x-ray radiograph and measure surrounding radiation loads if possible.

h. Describe the radiographic film developing process. Outline the steps involved, and state approximate dwell times for each step. (Assist in the development of the film, if possible.)

i. Describe methods of reducing scatter.

j. Demonstrate an understanding of personnel safety and radiation protection by reviewing a sketch and description of a typical radiographic test set-up, and list the following:
   (1) Recommended dosimetry
   (2) Personnel precautions
   (3) Calculated permissible "stay times" in radiation areas identified
   (4) Effect of shielding usage specified

k. Collect the data specified on Table 26-5-10 in the Data Table section of this module.

3. Procedure #3 - (In reference to Exercise #10)

a. Visit a welding shop in your area employing the use of radiographic testing of the completed welds.

b. Study the selected specimens to be radiographed.

c. Follow the procedure along with the RT technician(s) present.

d. Identify the radioisotope or x-ray source used.

e. Examine the radioisotope camera and accessories used.

f. Complete Table 26-5-11 in the Data Table section of this module. Table 26-5-11 contains all of the pertinent data to be collected regarding the RT method of NDE testing.

g. Prepare a short report on your visit.

DATA TABLE

The following tables are provided for the support of Exercise #8, #9, and #10 presented in this Module. Refer to the Procedures section for further details involving their use.

Table 26-5-9

Radiation Detection and Measurement Equipment

Date: ______________________

Site Visited: ____
____

Personnel Met: ____
____
____
____

Type of Detector Used	Range of Operation	Type of Source Used	Type of Radiation Detected

Table 26-5-10
X-ray Equipment Examination and Use

Date: ____________________

Site Visited: ____
____

Personnel Met: ____
____
____
____

X-ray Machine Type: ________________________________
____

X-ray energy: ____

Type of Photographic film used: ____________________

Recommended dosimetry: ______________________________

Personnel Precautions: ______________________________
____
____

Calculated permissible "stay-times" in radiation areas identified: ________________________________

Effect on shielding usage specified: ____________________
____

Table 26-5-11

Radiographic Test Site Visit and Inspection

Date: ________________________

Site Visited: ____

____

Personnel Met: ____

____

____

Type of specimens to be radiographed: ______________________

____

Source and film selection orientation and method of placement: ____

____

Penetrameter selection and usage: __________________________

____

____

Specimen identification method: ____________________________

____

Overlap and number of exposures: ___________________________

____

Type of shielding employed: ________________________________

____

Use of screens and filters: ________________________________

REFERENCE MATERIALS

Eastman Kodak Company. Radiography in Modern Industry, 1969

McGonnagle, Warren J., Nondestructive Testing, New York: McGraw Hill Book Company

Metals Handbook, Volume 11, Nondestructive Inspection and Quality Control, American Society for Metals

McMaster, Robert C. (ed.), Nondestructive Testing Handbook, New York: The Ronald Press Company

Overman, Ralph T., Basic Concepts of Nuclear Chemistry, New York: Reinhold Publishing Corporation

TEST

1. Complete the following statements:

   a. The movement of subatomic particles through space is known as __________.

   b. The movement of short electromagnetic waves of energy with the speed of light is known as __________.

   c. Two particles which are emitted from radioactive materials and have limited penetrating ability are __________ and __________.

   d. Two types of electromagnetic radiation which are used for radiographic testing are __________ and __________.

   e. Two types of gamma ray sources which are by-products of neutron bombardment are __________ and __________.

2. Indicate True or False for the following statements:

____ The "half-life" values of radioisotopes decrease with time.

____ The specific activity of source materials has no relation to resultant source size.

____ The specific activity of source materials may be measured in units of Curies per gram.

____ Short half-life is an undesirable quality for source material.

____ Radioactive source materials are encapsulated to permit safe and convenient handling.

____ Isotope cameras are never used for storing radioactive sources.

3. Select the correct answers to the following questions:

   a. What target material is most commonly used in X-ray tubes?

   (1) Uranium

   (2) Tungsten

(3) Sodium
(4) Aluminum

b. In an X-ray tube, a thermal conducting metal rod would be used for what?
(1) to heat-up the tube.
(2) to support the tube.
(3) to support the specimen.
(4) to remove heat from the target.

c. The duty cycle for any X-ray machine is dependent upon what?
(1) voltage and amperage.
(2) anode cooling.
(3) cathode deterioration.
(4) shielding thickness.

d. "Characteristic X-rays" are peculiar to what?
(1) the target material.
(2) the cathode.
(3) the velocity of the electron's.
(4) the specimen material.

e. A Cobalt-60, 20 Curie gamma source is obtained for radiographic use. What is its emissivity, measured at 1 foot?
(1) 29 R/Hr.
(2) 20 R/Hr.
(3) 200 R/Hr.
(4) 290 R/Hr.

4. Indicate True or False for the following statements:

____ Radiation dose rate is measured in curies.

____ Dosimeters measure dose rate directly.

____ The PIC dosimeter frequently has a scale graduated from 0-200 mR.

Before they are used to measure total radiation dose, dosimeters are "zeroed" by grounding or discharging the electrode or charging rod.

5. Select the correct word in the following statements:

a. Radiographic film density (increases) (decreases) proportionally with radiation exposure.

b. TLD's are (inferior) (superior) to film badges in recording whole body radiation exposure.

c. Radiation intensity in an area may be measured quickly with (TLD's) (survey meters).

d. Radiation survey meters operate on the principle of (ionization) (photoelectric effect).

6. Complete the following statements:

a. The accuracy of most radiation survey meters as about __________.

b. Survey meters which operate on the "gas amplification" principle are known as __________.

c. Geiger counters are inherently __________ sensitive than ionization chamber instruments.

d. A __________ of known intensity is used to calibrate radiation survey meters.

7. Fill in the blanks in the following statements:

a. Penetrating external radiation from X- or gamma ray sources is measured in __________ units.

b. The unit of penetrating radiation as applied to the exposure of human or animal tissue is the __________.

c. The biological effectiveness of fast neutrons absorbed by human tissue is __________ times as great as X-radiation.

d. Federal Regulations prohibit whole body exposures to penetrating radiation in excess of __________ per calendar quarter.

e. In a constant radiation field, the amount of absorbed radiation is __________ to the time exposed.

8. Given a 20 curie Iridium-192 source,
   a. what is the radiation dose rate at 1 foot?
   b. what is the dose rate at 10 feet?
   c. if a technician works at a distance of 10 feet from the source for 6 minutes, what dose will be receive?
   d. if the technician works at a distance of 15 feet from the source for 6 minutes, what dose will he receive?

9. Given a 50 curie source of Cobalt-60,
   a. what is the radiation dose rate at 1 foot?
   b. at what distance from the source will the dose rate be less than 100 mR/Hr?
   c. what is the radiation dose rate at 100 feet?
   d. at a distance of 100 feet from the source, how long may a technician work without receiving a radiation dose over 20 mR?

10. A radiation source of Cesium-137 is producing a radiation intensity of 1000 mR/Hr. To reduce the intensity to a safer working level of 125 mR/Hr., what thickness of shielding material is required to be placed between the source and the work area for:
    a. lead?

    b. steel?

11. The radiation intensity in an area is 400 mR/Hr, as emitted from a 200 kV X-ray tube. To reduce the intensity to 50 mR/Hr, what thickness of shielding material is required for:
    a. lead?

    b. concrete?

12. Indicate true or false for the following statements:

____ In radiographing an object, all rays emitted from the radiation source pass through the object and strike the film.

____ The object being radiographed must be placed close to the radiation source to minimize image enlargement.

____ In a radiograph, the "penumbra" is the image on the film representing geometric unsharpness.

____ The size of the radiation source has little effect on the sharpness of the resulting radiograph

____ The enlargement of the discontinuities in an object being radiographed increases as the source is moved further from the object and the film.

13. Select the correct answers in the statements as indicated:

a. Film image distortion can be minimized by making sure the radiation beam is __________ to the film.

(1) parallel
(2) behind
(3) perpendicular
(4) oblique

b. Film image distortion may interfere with __________.

(1) interpretation
(2) exposure time
(3) subject arrangement
(4) sensitivity

c. Geometric unsharpness is not affected by __________.

(1) source size
(2) source-to-film distance
(3) object-to-film distance
(4) exposure time

d. The intensity of the rays emerging from an object being radiographed varies with the __________ of the object.

(1) thickness
(2) density
(3) shape
(4) all of the above

14. Select the correct word in the following statements:

a. An image cannot be observed on a radiograph without adequate (density) (contrast).

b. Image sharpness on a radiograph is expressed as (definition) (subject contrast).

c. Film exposure is (greater) (less) at thicker areas of the object being radiographed.

d. Film contrast (is) (is not) affected by film density.

e. Differences in film density, as interpreted from a film "H & D" curve, are measures of (film contrast) (film speed).

15. Indicate true or false for the following statements:

____ Radiographic films should be exposed for the lowest practicable density to maximize film contrast.

____ Low speed films exhibit better grain and resolution characteristics than fast films.

____ Reversal may occur as a result of over exposure.

____ Film developing is not affected by temperature.

____ Stop bath solutions are used to save rinse water.

____ The action of the fixer solution, in the developing process, softens the gelatin on the film to improve flexibility.

____ Automatic film processors minimize manual handling of film and usually process film in less than 15 minutes.

16. Indicate true or false for the following statements:

____ Fluorescent screens are always used in high energy radiography for image intensification.

____ Metals with high atomic numbers are usually preferred for use as filters.

____ Scatter radiation may be limited with the use of masks and shields.

____ Penetrameters provide accurate measurements of film sensitivity.

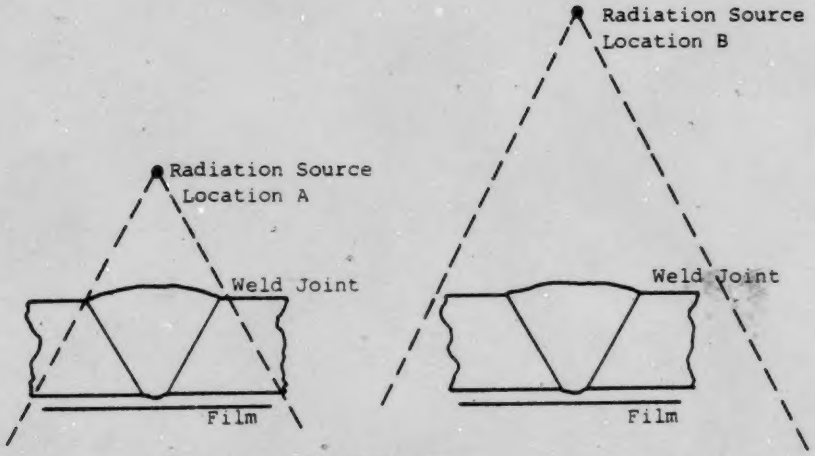
____ ASME Penetrameters provide for 3 different quality levels of inspection.

17. In radiography a 2" thick specimen, an ASTM 2-1T penetrameter as selected by the technician, and an acceptable radiograph was obtained. In the test situation,
    a. what is the thickness of the penetrameter used?
    b. which hole (or holes) in the penetrameter are visible?
    c. what is the diameter of each penetrameter hole?
    d. what is the equivalent penetrameter sensitivity?

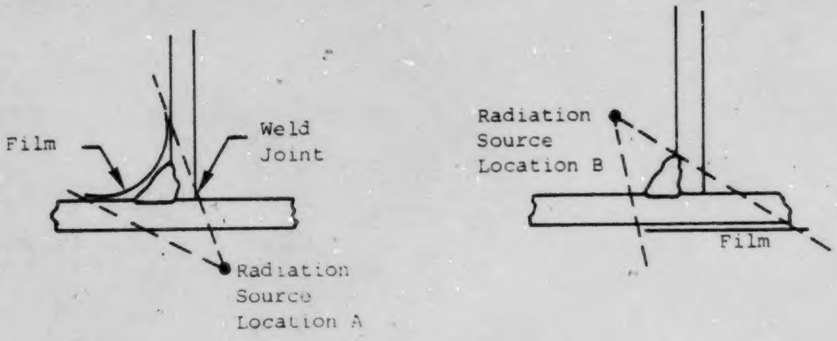
18. In radiographing a 1 1/2" thick weld joint, an equivalent penetrameter sensitivity of 1.0% was desired.
    a. what is the designation of the required penetrameter?
    b. what is the thickness of the penetrameter?
    c. what is the diameter of the smallest perceptible hole in the penetrameter?

19. For the radiographic exposure arrangements shown below, indicate which source location produces (1) minimum exposure time, and (b) minimum image distortion.

Arrangement	Radiation source location	
	Min. Expos. Time	Min. Distortion
1		
2		

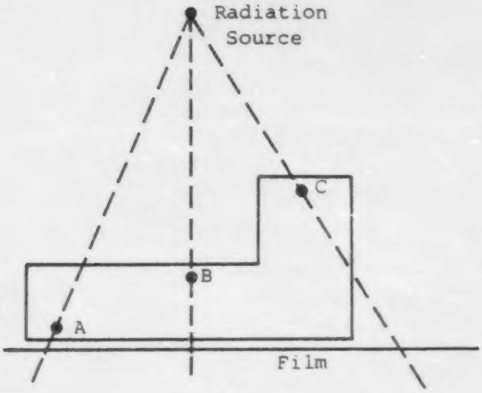

Radiation Source Location A
Weld Joint
Film
Radiation Source Location B
Weld Joint
Film

Arrangement 1


Film
Weld Joint
Radiation Source Location A
Radiation Source Location B
Film

Arrangement 2

20. In the radiographic arrangement shown below,
(1) which of the projected images of defects A, B, or C will be in sharpest focus? __________
(2) which of the images (A, B, or C) will have the greatest distortion? __________



21. Mark the following statements true or false as applicable:

____ With only a single radiograph, it is impossible to establish the location of a discontinuity observed in a superimposed image of a circumferential weld joint.

____ Increasing the source-to-film distance also increases exposure time.

____ Definition is usually improved when the source-to-specimen distance is increased.

____ A panoramic exposure of a large pipe circumferential weld may be made with the film placed on the inside surface of the pipe.

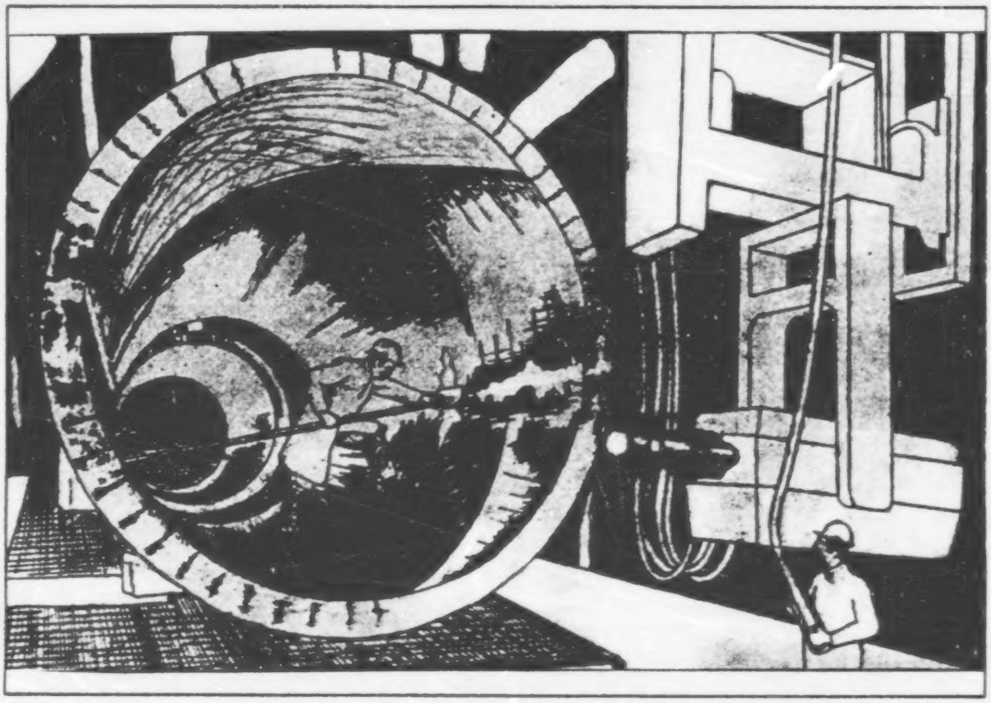
____ Increased exposure time, in radiographing an object with a large range of contrast, compensates fully and obviates the need for multiple exposures.

____ Small pipe welds may be radiographed successfully with a panoramic exposure, with the radiation source located inside the pipe.

NUCLEAR TECHNOLOGY

MODULE 26 - 6

RADIOGRAPH INSPECTION



COURSE 26: NONDESTRUCTIVE EXAMINATION (NDE)

CORD

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
4800 LAKEWOOD DRIVE WACO, TEXAS

COURSE 26 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES I

MODULE 26-1	Visual Tests
MODULE 26-2	Leak Tests
MODULE 26-3	Hydrostatic Tests
MODULE 26-4	Liquid Penetrant
MODULE 26-5	Fundamentals of Radiography
⇨ MODULE 26-6	Radiograph Inspection
MODULE 26-7	Radiographic Specifications and Code Requirements

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INTRODUCTION

Radiographic inspection, as covered in this module, is a means of nondestructively examining components, assemblies, structures and fabricated piping, and is widely used in the construction, maintenance and repair of power plants and petro-chemical plants, and for many other industrial applications.

In the broadest sense, radiography includes fluoroscopy (the viewing of a real-time image on a fluorescent screen), and radiation gaging (the measurement of radiation intensity with electronic instruments), but this module deals only with the process which produces a permanent image on film.

Module 26-5, "Fundamentals of Radiography", is prerequisite for this module, which, when both are completed, will equip the trainee with the knowledge to select the radiation source appropriate for the application, select a suitable radiographic film, be aware of personnel safety requirements, perform the necessary calculations to determine radiographic exposures, properly arrange sources, specimens and films, and to evaluate probable causes and corrections for unsatisfactory radiographs.

MODULE PREREQUISITES

Module 26-5 "Fundamentals of Radiography".

OBJECTIVES

To satisfactorily complete this module, the trainee shall:

1. Demonstrate a knowledge of the fundamentals of radiography inspection by responding correctly to written exercises, which are similar to the questions included in the American Society for Nondestructive Testing SNT-TC-1A Level II certification written test.
2. Demonstrate a knowledge of exposure calculations and controls by performing calculations and/or determining: steel-equivalent thickness, absorber factors, source activity, source-to-film distances, gamma ray and x-ray exposure times.
3. Demonstrate a knowledge of exposure arrangements by answering written questions about typical arrangements, and labeling sketches of arrangements to show source location, penetrameter location and film location.
4. Demonstrate a knowledge of radiographic image defects and film artifacts by answering written questions about errors in techniques, film handling, and film processing.
5. As a laboratory exercise, given a metal part, such as a machined part, gear, welded pipe, or similar object by the instructor, the trainee shall prepare a diagram and procedure for radiographing the object, and using the information in this text, write a radiographic test report including the following detailed information:
   a. Source: type, strength, reason for selection.
   b. Test specimen: material type, thickness (area to be radiographed), absorber factor.
   c. Sketch of test arrangemetn: source location, film penetrameter.
   d. Exposure time and supporting calculations.
   e. Suggested film processing procedure.
   f. Recommended personnel safety precautions for radiation protection.

SUBJECT MATTER

RADIATION SOURCE SELECTION

General

Most industrial radiography is performed with either x-ray machines used as radiation sources, or with gamma ray emitting radioisotopes. Commercial testing companies, which specialize in furnishing nondestructive testing services, may have several different sizes of x-ray machines, and several types and sizes of radioisotopes for use in providing a broad range of radiographic testing services for their customers. When such a variety of equipment is available, the radiographer can select the radiation source best suited for each specific application. In most industrial situations, however, only one or two radiation sources are available, and the radiographer has little or no choice. Nonetheless, the radiographer should be familiar with the energies emitted, penetrating capabilities, and other characteristics of the most commonly used radiation sources, and how to utilize those characteristics to the best advantage.

Radiation Source Energies

The production of x-rays is a function of the voltage on the x-ray tube: the higher the voltage, the shorter the wavelength of the radiation produced, and the greater the intensity and penetration power of the radiation. X-ray machines, then, are rated by the nominal maximum operating voltage of the particular x-ray tube, such as 150 KV (Kilovolt), 300 KV or greater.

The penetrating power or capability of commercial x-ray machines is shown in Figure 26-6-1, where the nominal x-ray tube operating voltage is plotted against the effective penetrating ability using film packs with (1) lead screens and (2) fluorescent screens in radiographing steel specimens. Screen usage will be discussed later in this module. (Please refer to the next page for Figure 26-6-1.)

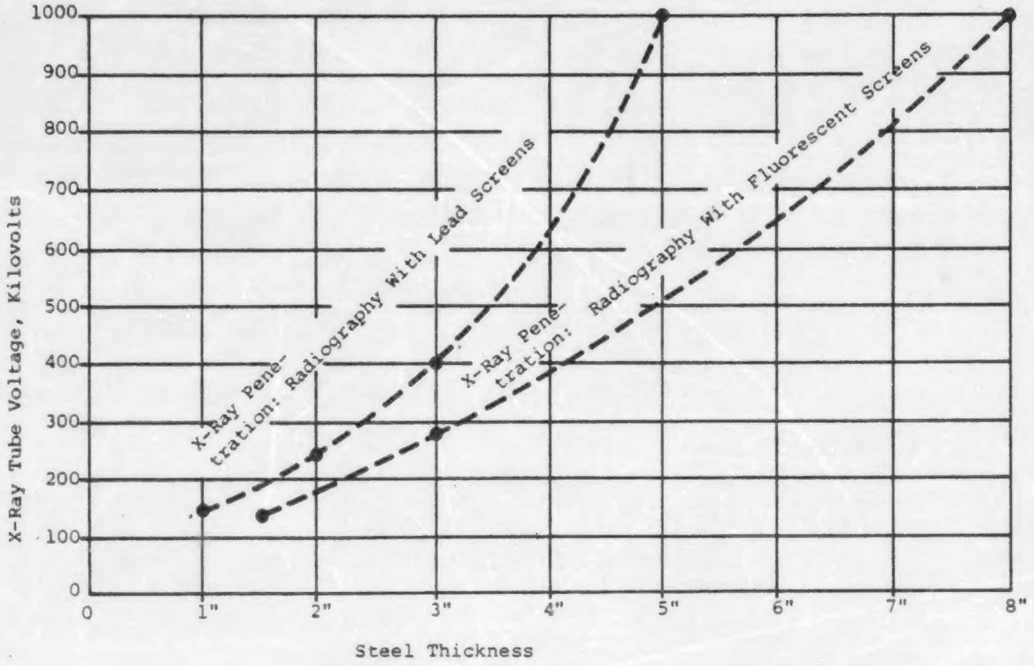


Figure 26-6-1. X-Ray Penetration in Steel: Radiographic Effectiveness

Gamma rays, emitted from radioisotopes, are expressed in terms of the energy of the individual quantum emitted, rather than wavelength. The unit of energy used is the electron volt (ev). In describing gamma radiation, multiples of electron volt terms are used, such as kilo-electron volts (kev) and million-electron volts (mev). (1 kev = 1,000 ev, and 1 mev = 1,000,000 ev) Some radioisotopes emit only one-energy gamma rays, but others may emit two or more different-energy gamma rays. These energies are usually described in units of million-electron volts (mev). It is a property of such emitted radiation that the higher the gamma energy, the greater the penetrating power.

The characteristics of some gamma sources are listed in Figure 26-6-2.

Isotope	Half-Life	Gamma Energies Emitted (Mev)	Specific Activity Curies/Gram	Emissivity @ 1 Ft. R/Ci/HR
Cesium - 137	30 Years	0.66	Up to 22	4.20
Thulium - 170	120 Days	0.054 & 0.084		0.03
Iridium - 192	75 Days	0.137 to 0.651	Up to 500	5.92
Cobalt - 60	5.3 Years	1.33 & 1.17	Up to 150	14.53
Radium - 226	1620 Years	0.24 to 2.2	1	9.04

Figure 26-6-2 Characteristics of Gamma Ray Sources

The isotopes most frequently used as sources for industrail radiographic work are Cobalt-60 and Iridium-192. These isotopes are preferred for their:

- high gamma ray energy (penetrating power), and
- high specific activity (resulting in small source size).

Cobalt-60, with gamma energies of 1.17 and 1.33 Mev has penetrating power equal to that of a 2 million volt x-ray machine, and may be used effectively in radiographing steel section from 1-1/2" to 9" thick, with a sensitivity of 2%.

Iridium-192, with primary gammas of 0.33 and 0.48 Mev, and several near 0.6 Mev, has penetrating power approximately equal to that of a 500 kilo volt x-ray machine, and may be used in radiographing steel from 3/8" to 3" thick, with a sensitivity of 2%.

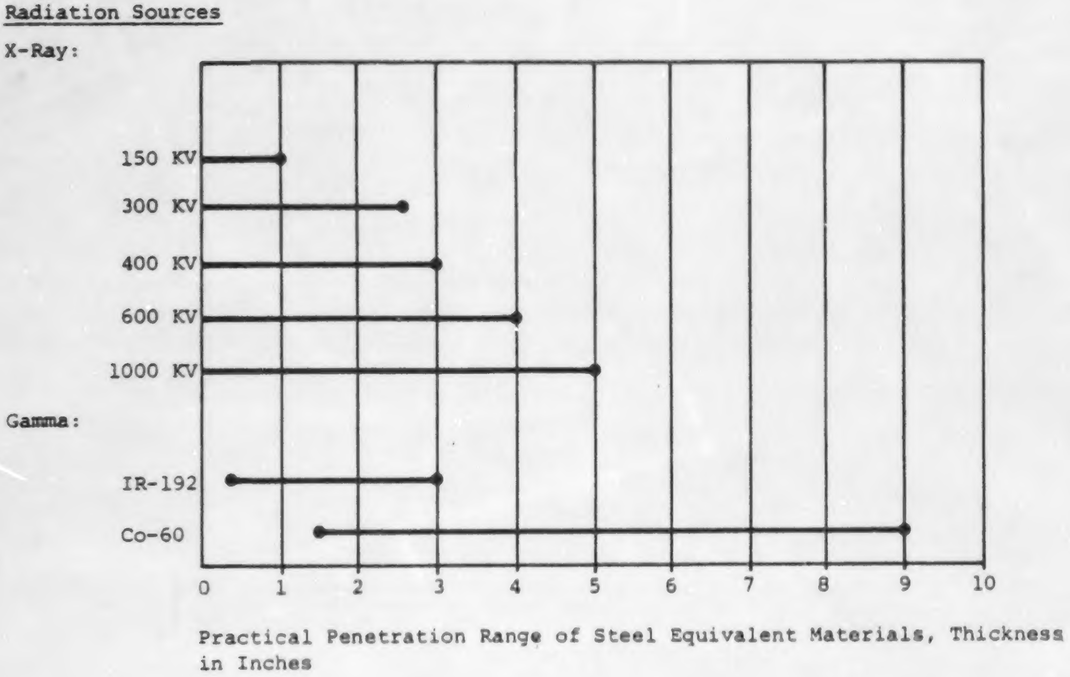
The penetrating power of any radiation is referred to as a relative hardness. Thus, very penetrating radiation is known as hard radiation, and less penetrating radiation is called softer radiation.

Summary

Applicability of radiation sources - The radiation sources in this section are listed in Figure 26-6-3 with their recommended ranges for radiographing equivalent steel materials. (Please refer to the next page for Figure 26-6-3.)

MATCHING RADIATION SOURCES TO SPECIMEN REQUIREMENTS

In selecting radiation sources, consideration must be given to specimen shape, configuration and location, and desired radiographic quality. Pipes, pressure vessels, valve bodies, structural steel welds and other typical specimens all require different "shooting" arrangements with respect to the radiation source location and placement. The actual location and elevation of the specimen, and interferences with other stationary piping and equipment are also factors which must be considered. In controlling radiographic quality, the source must be selected which will provide the required sensitivity and radiographic contrast. In using gamma sources, radiographic contrast can only be influenced by varying the exposure. In using x-ray machines, however, contrast is affected by both exposure and kilovoltage: an



Note: 1. All exposures made with lead screens only.

2. For specific steel equivalent factors, see Figure 26-6-7.

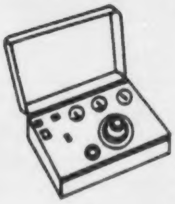
Figure 26-6-3 Radiation Source Applicability

increase in kilovoltage increases contrast, and a decrease in kilovoltage decreases contrast.

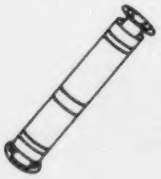
X-ray laboratories are suitable for radiographing specimens which can be moved to the facility. For this situation, an x-ray machine can be selected that will produce radiation capable of making the maximum required exposure, and the laboratory, or shielded area where the equipment will be used, designed accordingly.

Except for low voltage units, however, x-ray machines are large, heavy and unwieldy, and are unsuitable for use in many industrial situations. The units usually consist of a control panel, interconnecting cables, and an x-ray head, which must be set-up in such a manner as to direct the x-ray beam at the specimen target.

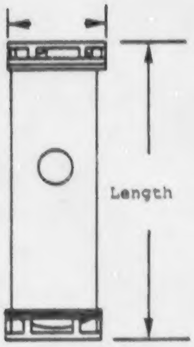
A typical x-ray control panel and head are shown in Figure 26-6-4, along with a chart of typical x-ray head sizes and weights.



X-Ray Control Panel



X-Ray Head



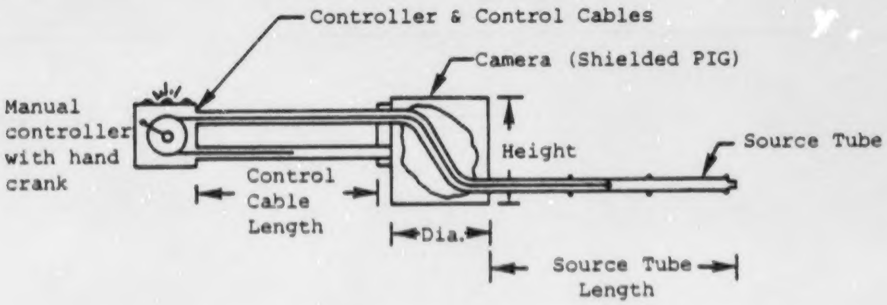
Typical X-Ray Head

KV.	DIA.	Length	Wt., Lbs.
150	10"	24"	55
200	12"	30"	75-90
225	12"	36"	75-110
250	12"	36"	90-125
300	13"	46"	105-150

Figure 26-6-4 X-Ray Machines

Radioisotopes for radiographic use are generally used with equipment which is more portable than the x-ray equipment. No external power is required, and the source is handled remotely by operating a controller. The controller is attached to the "camera" (shielded storage device or "pig") and causes the radioactive "source" to move out of the camera into the extended source tube, which has been positioned to locate the source for the effective exposure of the specimen.

Typical cameras, controls and source tubes for Ir-192 and Co-60 sources are described in Figure 26-6-5.


Controller & Control Cables
Camera (Shielded PIG)
Manual controller with hand crank
Height
Source Tube
Control Cable Length
Dia.
Source Tube Length

Gamma Source Camera & Attachments

Typical Equipment Specifications

Source	Camera			Control Cable Length	Source Tube Length
	Ht.	Dia.	Wt., #		
Ir-192, 35 Ci	7½"	5½"	25	25'	15'
Ir-192, 100 Ci	8"	5½"	32	25'	25'
Co-60, 5 Ci	12"	11"	150	30'	23'
Co-60, 50 Ci	20"	13"	300	30'	23'

Figure 26-6-5 Typical Gamma Source Equipment

It should be noted that the source tubes are flexible and may be moved in any direction from the camera. Heavy cameras, such as those for Cobalt-60 sources, are usually wheeled on a dolly as close to the specimen being radiographed as possible. Light weight cameras, such as those shown for Iridium-192, may be carried easily by the radiographer to the test location. In either case, the source tube can be positioned in virtually inaccessible or hard to reach locations where x-ray equipment could not be used. The size of the camera (shielded PIG) must be sufficient to provide proper biological shielding for the technician when it is not in use. A manual crank controller is generally used as is shown in Figure 26-6-5, thus enabling the user properly position the source and once again retract it into the shielded PIG. "Source-in" and "source-out" lights are employed to provide indication of source position.

FILM SELECTION AND USAGE

Film Types

Radiographic films are manufactured with different characteristics to suit different applications. Generally, they are classified by quality (grain size) and speed (relative sensitivity). The coarser the grain size of any film usually corresponds to a faster film speed, or greater sensitivity.

Contrast varies with film type, and generally increases with increasing density. A minimum film density of 1.5 is usually required for most industrial applications, and darker films are desirable if the viewing equipment has sufficient light intensity.

"Film factors" are statements of radiation dosage required to expose a film to a specified density compared to some other film accepted as a standard. Figure 26-6-6 shows relative film factors and comparative contrasts of typical films used by industry.

Film Type	Density			
	1.5	2.0	2.5	3.0
Medium Speed (Fine Grain) Kodak Industrex AA Dupont NDT 75 GAF 1600	3.6	5.1	6.6	14.9
Low Speed (Extra Fine Grain) Kodak Industrex M Dupont NDT 55 GAF 400	14.5	20.8	27.3	34.3

Figure 26-6-6 Film Factors (Estimated)

For medical radiographic work, a fast, coarse grain film is desirable for minimizing exposure times and the attendant absorption of harmful radiation by the patient.

In most industrial applications, however, fine grain or extra fine grain films are used, which provide greater contrast and higher radiographic quality.

It is advisable to refer to manufacturer's specifications for specific characteristics and comparison of grain sizes and relative speeds.

Film Packaging

Radiographic films are available in a variety of sizes and packages, the basic types being sheet films and roll films.

Both types are light sensitive and must either be purchased in individual, sealed, ready to use packets, or be purchased loose in light-tight cartons (e.q., units of 125 or 500 sheets per carton) and loaded into light proof envelopes called cassettes or other types of film holders in the protection of a darkroom, prior to use.

- Sheet Films - Sheet films are furnished in rectangular shapes and are available in widths from about 3-1/2 to 14 inches and lengths from about 7 to 17 inches. They may be purchased in loose, bulk packages, or in individual light proof packages, ready to use. The individual film packages are available as (1) single film sheet packs, for direct exposure techniques, and (2) lead packs, which contain a single film sheet inserted between two lead oxide screens, for intensification techniques. Both types of film packs eliminate the time-consuming process of darkroom loading of film holders and cassettes and protect the film from fingerprints and dirt up to the time the film is removed from the pack for processing.
- Roll Films - Roll Films are useful in radiographing circumferential welds and other long joints. Bulk roll films are available in various widths, and in various lengths up to about 550 feet. They may also be purchased pre-packed in plain, light-proof paper packs, and in lead-packs with lead oxide screens. Roll film packs such as these offer the same advantages and convenience as described for sheet film packs.

PERSONNEL SAFETY CONSIDERATIONS

The absorption of ionizing radiation produces physiological changes and damage to the human body. All personnel must therefore be protected from exposure to x or gamma radiation. Radiography must be conducted in restricted areas when possible, under controlled conditions, and under the supervision of properly qualified personnel.

The use of radioisotope sources (by-product materials) is controlled by the Federal Government. Specific licenses are required to use by-product materials. All persons who "manufacture, produce, transfer, receive, acquire, own, possess, use, import, or export" by-product material must have such a license. The regulations concerning the licensing of by-product material for use in radiography are contained in Title 10, Code of Federal Regulations, Parts 30 and 34.

The radiation safety requirements for radiographic operations, using radioisotopes, are contained in Title 10, Code of Federal Regulations, Part 34. The rules require the license to have operating, emergency and precautionary procedures to radiographic operators, including procedures for personnel monitoring, equipment security, radiation surveys and radiation monitoring.

Regulations and safety rules are drawn to limit personnel radiation exposures to a point far below danger levels and to afford acceptable protection for the general public of the United States. These rules are contained in Title 10, Code of Federal Regulations, Part 20.

The Federal Regulations described herein are specifically invoked for the use of by-product materials. The regulations are applicable to x-ray operations only when isotope radiography is also used. Even when a radiography program includes only x-ray equipment and operations, however, the basic principles for personnel safety remain the same, and the rules should be used as guidelines for radiographic operations and a radiation safety program.

SUBJECT EXPOSURE CALCULATIONS AND CONTROL

Radiation Absorption Characteristics of Specimens

When x-rays or gamma rays strike a specimen, part of the radiation is absorbed by the material and part passes through. The radiation absorption is dependent on the specimen thickness, density and atomic nature of the material. The amount of absorption of x-rays is also a function of kilovoltage and penetrating power, as the absorption of gamma rays is a function of emitted energies and penetrating power.

To assist the radiographer in equating various materials, radiographic equivalence factors have been determined for different radiation sources. Some of these are listed in Figure 26-6-7.

NOTE: Steel is taken as the standard metal for the voltages and radioisotopes shown. The thickness of another metal is multiplied by the corresponding factor to obtain the approximately equivalent thickness of the standard metal (steel). The exposure required for this thickness of the standard metal is then used. This relationship of various materials to the radiation absorbance characteristics of steel is known as "steel equivalent thickness".

In calculating initial radiographic exposures using gamma-ray sources, it is convenient to use a chart of "absorber values" for determining absorber values for different radioisotopes and for different material thicknesses. The absorber values for sources of Ir-192 and Co-60 have been

	X-Rays				Gamma-Rays	
Material	150 KV	220 KV	400 KV	1000 KV	Ir-192	Co-60
Steel	1.0	1.0	1.0	1.0	1.0	1.0
2024 Alum. Alloy	0.16	0.22			0.35	0.35
Copper	1.6	1.4	1.4		1.1	1.1
Inconel x Alloy	1.4	1.3	1.3	1.3	1.3	1.3
Zirconium	2.3	2.0		1.0		
Lead	14	12		5	4.0	2.3

Figure 26-6-7 Approximate Radiographic Equivalent Factors (Or Steel Thickness Factors)

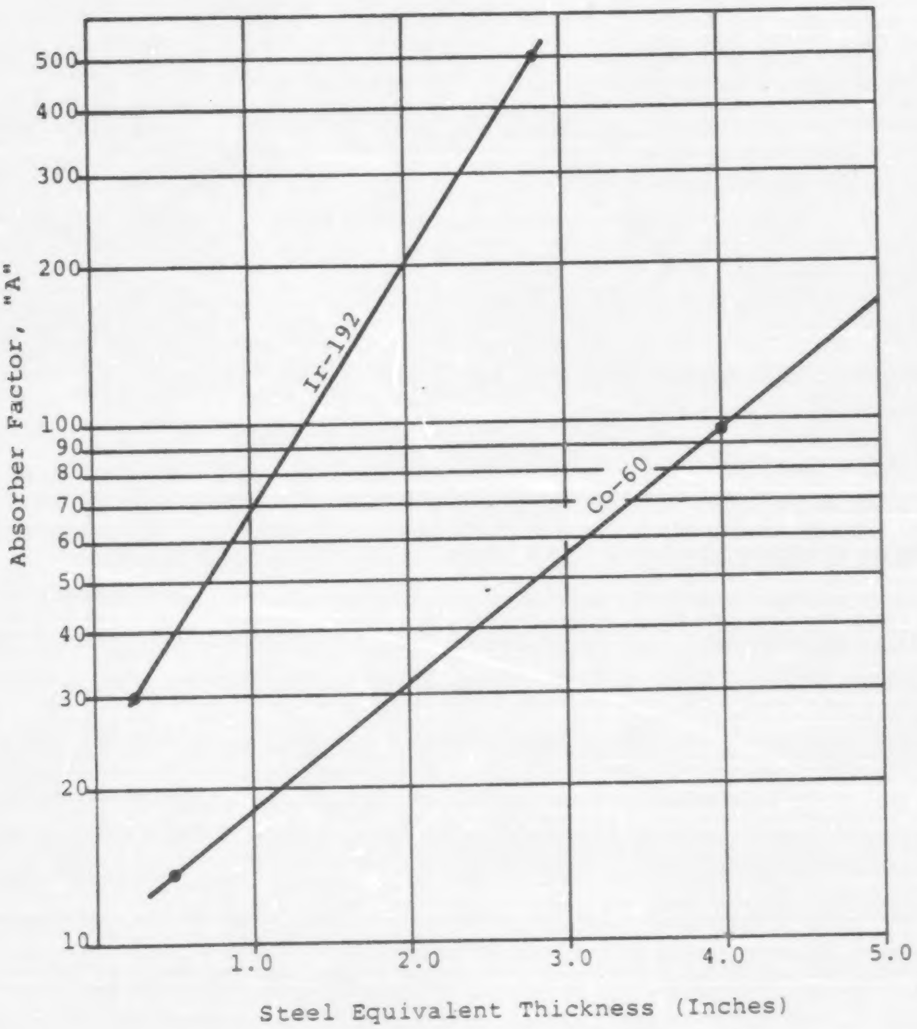


Figure 26-6-8 Absorber Values for Sources of Ir-192 and Co-60 Plotted as a Function of Steel Equivalent Thickness

plotted for a range of steel equivalent thickness and are shown in Figure 26-6-8. The steel equivalent thickness value for the specimen material can be obtained by multiplying the specimen thickness by the appropriate factor listed in chart, Figure 26-6-7.

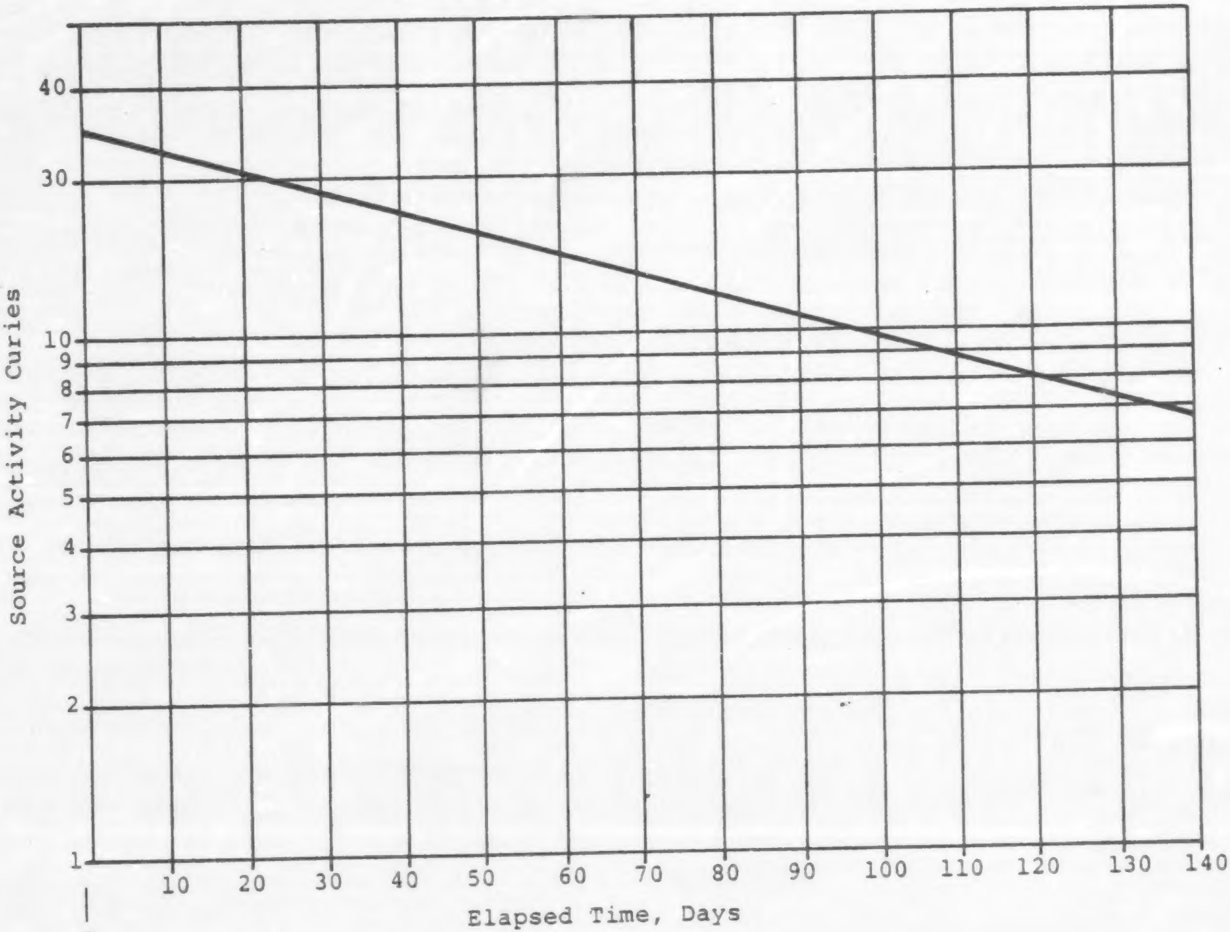
Source Emissivity

Darkening of the radiographic film is determined by the total amount of radiation reaching the film.

The total amount of radiation emitted from an x-ray tube depends on tube kilovoltage, current (milliamperage) and the time the tube is energized. The x-ray output is directly proportional to both milliamperage and time, and, therefore, is directly proportional to their product. This product is referred to as the "exposure", and is usually expressed in units of milliampere-minutes.

The total amount of radiation emitted from a gamma-ray source is approximately proportional to the source activity (usually stated in curies) and the time of the exposure. The proportional relationship of source sizes is not exact due to absorption of gamma-rays within the radioactive material itself (self-absorption). In normal practice, however, the source sizes used are not substantially different enough to cause large variations from proportionality. The variations are usually ignored, and, thus, the gamma-ray output is directly proportional to both the activity of the source and time, and is also directly proportional to their product.

When gamma-ray source is delivered to a user by the supplier, it is supplied with a dated source activity (strength) chart, such as shown in Figure 26-6-9. The chart is used to determine the source activity on the day that the exposure is to be made. For example (refer to Figure 26-6-9) on the 30th day following the date of calibration, the source activity is 19 curies.



Source: Ir-192 Half-life: 75 Days
Activity: 25 Curies
Date of Calibration: 3/31/78
Supplier: Rad-Industries
Calibrated By: R.G.

Figure 26-6-9 (Typical) Source Activity Chart

USE OF RADIOGRAPHIC SCREENS

The formation of radiographic images is governed by absorbed radiation. Usually less than 1 percent of the energy emitted from a gamma or x-ray source is absorbed by a film. The balance of the energy is wasted. Radiographic screens are usually employed to utilize part of that wasted energy and intensify the photographic action on the film.

Two types of radiographic screens are used: lead screens and fluorescent screens.

Lead screens consists of lead foil sheets thicknesses of from about 0.004 to 0.010 inches, and are used in direct contact with both sides of the film. This arrangement produces three principal effects: (1) increases the photographic action on the film, (2) absorbs longer wavelength scattered radiation, and (3) intensifies the primary radiation more than the scattered radiation.

Typically, with gamma and x-radiography, the front lead screen used is 0.005 inch, which provides the intensifying action, and the back screen is 0.010 inch, which absorbs back-scatter.

The intensification achieved with the use of lead screens depends on the material radiographed, the material thickness, and the radiation quality or kilovoltage. For example, in the radiographing of 1-1/4 inches of steel with x-rays of about 200 KV, lead screens permit an exposure of about 1/3 of that without screens, or an intensification factor of 3. In radiographing the same material with gamma rays, the intensification factor is about 2.

Fluorescent screens are thin, composite sheets consisting of special cardboard glazed with a mixture of fully powdered materials which have the ability to absorb x-rays or gamma rays and emit light (fluoresce). They are used by clamping a radiographic film tightly between a pair of these screens during exposure. The photographic effect is intensified because it is the sum of the effects of the source radiation and the light emitted by the screens.

Fluorescent screens are seldom used in industrial radiography because they tend to give excessive graininess to the image and produce poor definition. They may be used on occasion in radiographying light metals or when economy demands significantly shorter exposure times.

CONTROLLING GEOMETRIC UNSHARPNESS

The arrangement of the position of the radiation source, specimen and film will determine the geometric unsharpness.

Two "rules of thumb" are used as guides in arranging geometry of techniques:

1. The source-to-film distance should be equal to greater than 8 times the specimen thickness. Smaller ratios than 8 will cause undesirable distortion.
2. The source-to-film distance should be equal or greater than the diagonal length of the radiograph, or as in the case of a narrow subject such as a weld zone, the length of the subject.

Examples

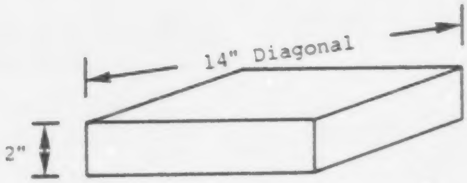


Figure 26-6-10 Steel Plate - 2" Thick, 14" Diagonal

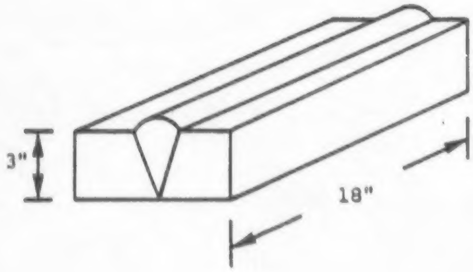


Figure 26-6-11 Welded Plate - 3" Thick, 18" Length

GAMMA RAY EXPOSURE

Many variables must be considered and controlled each time a radiograph is made. Exposure times may be determined by trial and error, but that technique is costly and time consuming. Most radiographic film manufacturers publish exposure guides for their respective films which can be used to determine approximate exposure times for the various factors of specimen material and thickness, source type and strength, and source-film distance. If these charts and guides are not available, the following calculation method may be used to determine the appropriate exposure time:

Equation A $$T = \frac{FAD^2}{S}$$

Where: T = Exposure time (minutes)
F = Film factor (See chart, Figure 26-6-6)
A = Absorber factor (See curve, Figure 26-6-8)
D = Source to film distance (inches)
S = Source activity (millicuries, Figure 26-6-9)

This calculation is based on the use of lead intensifying screens in the film pack, 0.005" front, and 0.010" back.

In using Equation A, the following steps should be used:

1. Identify the material to be radiographed, and refer to Figure 26-6-7, Radiographic Equivalence Factors. For the gamma-ray source to be used (Ir-192 or Co-60) determine the steel-equivalent-thickness factor (e.g., 2024 Alum. Alloy with Ir-192, factor = 0.35).
2. Measure the specimen absorption path thickness (radiation path distance through the specimen) and convert that specimen thickness to a "steel-equivalent-thickness" by multiplying the specimen thickness by the steel-equivalent thickness-factor as determined in (1) above.
3. Determine the absorber factor "A" (for Equation A) as follows - Refer to chart, Figure 26-6-8: from the curve for the selected source (Ir-192 and Co-60) and the calculated steel-equivalent thickness, read the value of the absorber factor, "A".
4. Determine the film factor "F" (for Equation A) as follows - Refer to table, Figure 26-6-6: for the film type to be used, and the desired density, read the value of the film factor.
5. Determine the source-to-film distance, "D", in inches (for Equation A) by measuring the longest specimen dimension and the specimen thickness (for Equation A).
6. Determine the selected source activity, "S", (for Equation A) as follows - Refer to the Source Activity Chart (or Source Calibration Chart) as furnished by the source supplier. (e.g., see the Typical Source Activity Chart, Figure 26-6-9, which represents an Ir-192 source of 25 curies, when calibrated.) Count

the number of calendar days from the date of calibration to the present, and read the present source activity from the chart. Note that the chart is plotted in units of curies. Convert the value in curies to millicuries by multiplying by 1000 to obtain the source activity value "S".

7. Calculate the exposure time, "T", by substituting the numerical values into Equation A, $T = \frac{FAD^2}{S}$.

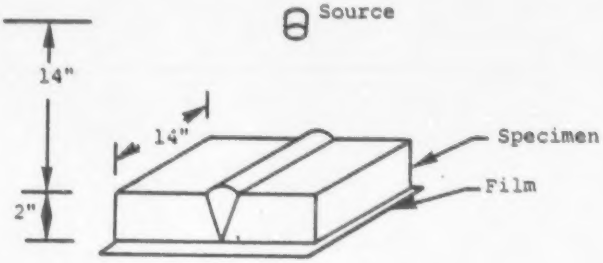


Figure 26-6-12 Gamma Ray Exposure Set-Up

Calculate the gamma ray exposure for the set-up shown in Figure 26-6-12 using the equation $T = \frac{FAD^2}{S}$, and the following materials and factors:

- Film - Medium Speed
- Density - 2.5
- Source - Ir-192 (use Source Activity Chart, Figure 26-6-9)
- Material - 2024 Aluminum Alloy

1. Determine "A", absorber factor - Refer to chart, Figure 26-6-7. For 2024 Aluminum alloy and Ir-192 source, the steel-equivalent thickness factor is 0.35. Convert the specimen thickness (2") to the steel-equivalent thickness: 2" x 0.35 - 0.70".

   Refer to chart, Figure 26-6-8. For a steel-equivalent thickness of 0.70", determine the absorber factor "A" by reading from the Ir-192 curve. "A" = 49.

2. Determine "F", film factor - Refer to table, Figure 26-6-6. For medium speed film and a desired density of 2.5, read the film factor. "F" - 6.6.
3. Determine "D", source-to-film distance - Refer to the set-up illustration, Figure 26-6-12. The specimen thickness ratio is: 2" x 8 = 16". The specimen length is 14". The minimum source-to-film distance, "D", = 16".
4. Determine "S", source activity. Refer to chart, Figure 26-6-9, for this example. Assume that 40 days have elapsed since the source was calibrated and the chart was produced. Reading from the chart, the present source activity is 17 curies. Converting this value, "S" = (17 x 1,000) = 17,000 millicuries.
5. Reiterating the factor values:

   F = 6.6
   A = 49
   D = 16
   S = 17,000
6. Substituting in the equation:

$$T = \frac{(6.6)\ (49)\ 16)^{2}}{17,000} = 4.87 \text{ minutes, or } 4.9 \text{ minutes}$$

X-Ray Exposure

The penetrating power of an x-ray machine is a function of x-ray tube operating kilovoltage, as formerly discussed (see Figure 26-6-1).

X-ray tubes are designed to operate at specific voltages (or kilovoltages), which vary between different manufacturers. The amount and quality of the penetrating radiation emitted from different tubes may be quite different, even though they are operating at the same current. and the same nominal voltage. Consequently, it is difficult to formulate a mathematical relationship, or equation, that can be used to calculate precise exposure times for all types of x-ray machines. Exposure charts are usually available from the film and x-ray machine manufacturers which may be used as guides. It is usually necessary for the radiographer to make trial and error exposures and develop x-ray technique curves for using the particular x-ray machine or different films and densities. The information obtained may also be used to correct or adjust the manufacturer's charts. See typical X-Ray Exposure Chart, Figure 26-6-13. (Please see next page for Figure 26-6-13).

An x-ray tube has an energy emission rate determined by the tube current, milliamperage (ma). The film exposure is the product of the beam intensity and time in minutes (min). The exposure then is expressed in ma-min (milliampere-minutes). Up to the maximum tube current specified by the manufacturer, the radiographer may select any ma value. This selected ma value divided into the milliampere-minute obtained from the X-Ray Exposure Chart (such as Figure 26-6-13) will determine the exposure time in minutes.

Example: X-Ray Exposure Calculation

Calculate the approximately exposure for the steel specimen shown in Figure 26-6-14.

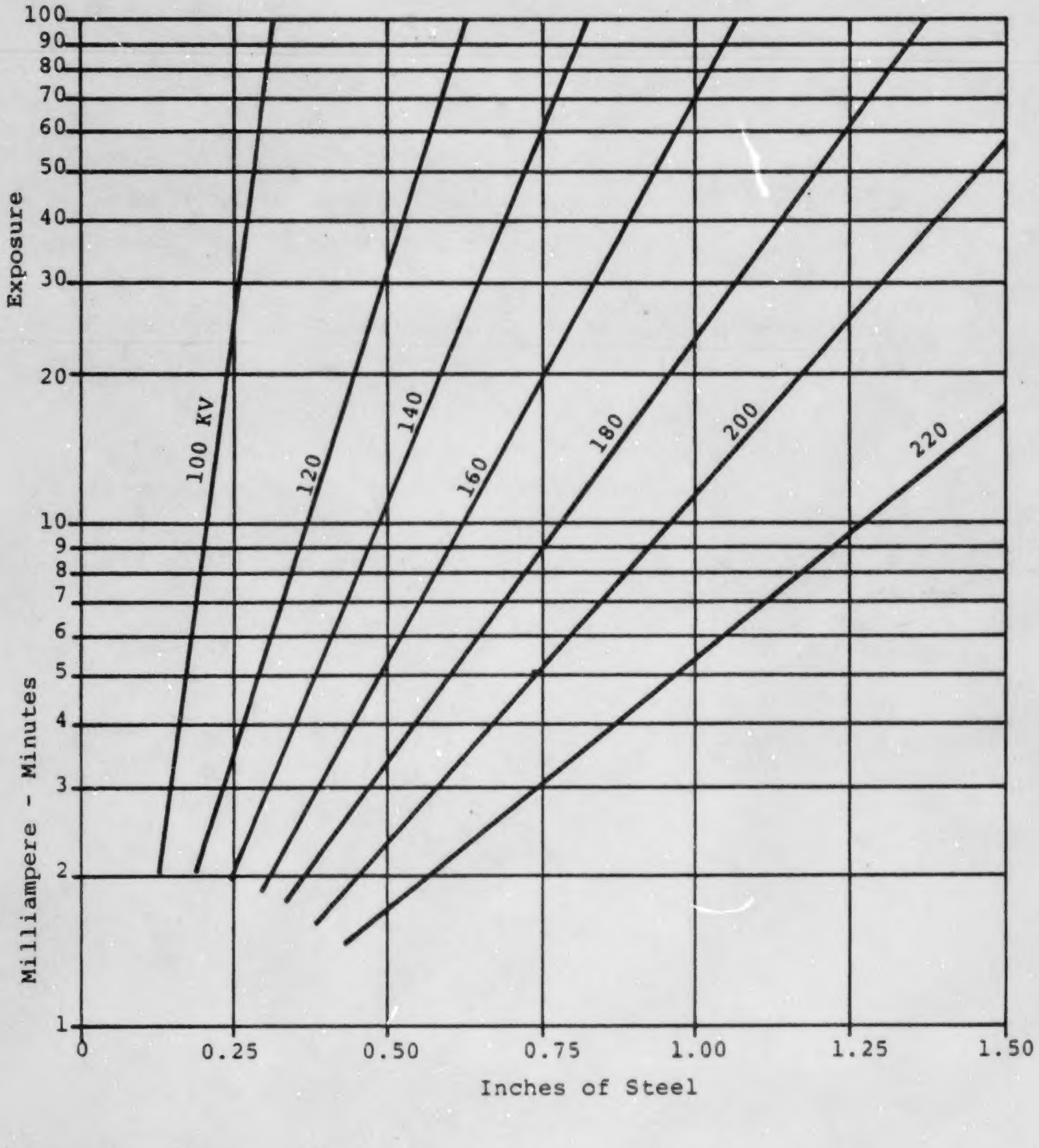


Figure 26-6-13 Typical X-Ray Exposure Chart
For: 220 KV X-Ray Machine
Film Density - 1.5 Film Speed - Fast
Material - Steel
Film Focus Distance - 40"

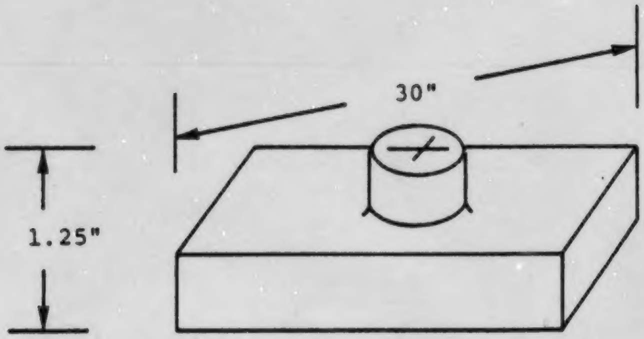


Figure 26-6-14 Machined Steel Plate With Boss

1. As Figure 26-6-14 shows, the maximum specimen thickness is 1-1/4" and the diagonal measure is 30". Applying the rules-of-thumb:
   - thickness ratio - 1.25" x 8 - 9" min source-to-film distance
   - diagonal measurement - 30" min source-to-film distance minimum source-to-film distance is 30"
2. A 220 KV x-ray machine is available for use, and a fast film has been selected for the radiograph. Refer to the X-Ray Exposure Chart, Figure 26-6-13. As the chart shows, voltage settings from 180 KV to the maximum 220 KV will penetrate the specimen. To minimize the exposure, a setting of 220 KV is selected. Reading from the chart (cure for 220 KV @ 1.25") the exposure is 9.5 ma-min.

   Notice that the chart was prepared using a source-to-film distance of 40". Since for this specimen a source-to-film distance of only 30" is being used, the radiant energy will be more intense, and a correction must be made. Using the inverse square law:

$$\frac{(\text{ma} - \text{min})_1}{(\text{ma} - \text{min})_2} = \frac{D_1{}^2}{D_2{}^2}$$

Where: $(\text{ma} - \text{min})_1 = 9.5$

$(\text{ma} - \text{min})_2 = \text{unknown}$

$D_1 = 40$

$D_2 = 30$

Substituting in the equation,

$$(\text{ma} - \text{min})_2 = \frac{(9.5)\ (30)^2}{(40)^2} = 5.34 \text{ ma} - \text{min}$$

If the milliamperage control is set for 5 ma, the exposure time "T" is calculated as follows:

$$T = \frac{5.34 \text{ ma} - \text{min}}{5 \text{ ma}} = 1.07 \text{ min, or 1 min. 4 sec.}$$

CONTROL OF SCATTER

Scattered radiation cannot be completely eliminated, but may be reduced to minimize loss of image resolution.

The most convenient and least expensive method of combatting the effects of scattered radiation is the use of lead screens, as previously described. Lead screens mounted in contact with both sides of the film reduce the scatter reaching the film regardless of whether the screens permit a decrease or necessitate an increase in the radiographic exposure.

For thick specimens or specimens having high absorption of x-rays or gamma rays, the scattered radiation from external sources may be high compared to the primary radiation reaching the film through the specimen. Such scatter may be reduced by the use of a sheet lead mask cut-out and placed around the specimen.

Lead diaphragms may be used near the radiation source to limit the cross-section of the primary beam to the shape or size of the specimen, and may be used to mask unwanted parts of a specimen when only a part of the specimen is to be radiographed, thereby minimizing the scattered radiation.

EXPOSURE ARRANGEMENTS

The quality of the radiograph is determined by the proper location of the source and film with respect to the specimen.

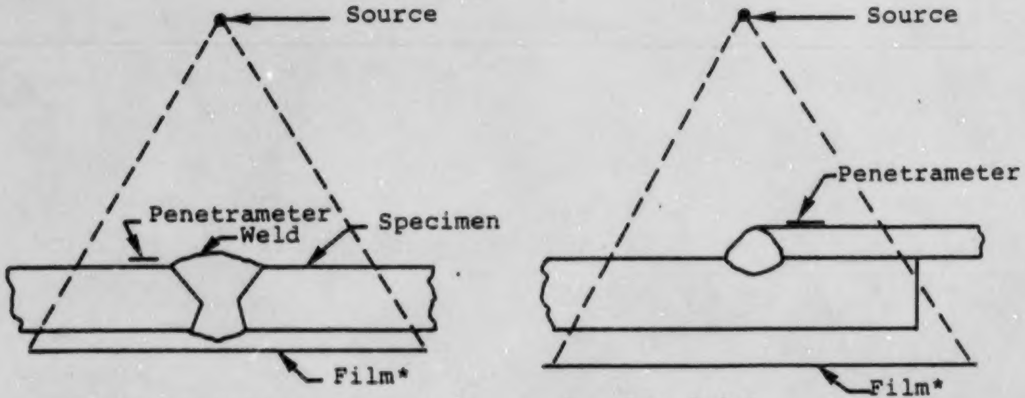
The exposure arrangement should be selected by the radiographer to:

1. Produce the best radiographic contrast of the specimen area that is likely to contain manufacturing discontinuities.
2. Produce the best radiographic contrast of the specimen area that is likely to fail in service (under imposed operating stresses).
3. Permit the shortest exposure time.

Typical industrial situations and arrangements are shown as follows:

Welded Flat Plates

A flat weld area such as shown in sketch A and sketch B in Figure 26-6-15 represents subjects easily radiographed, with the critical areas well defined in length, width and thickness, with minimal subject contrast.



A. Butt Joint B. Lap Joint

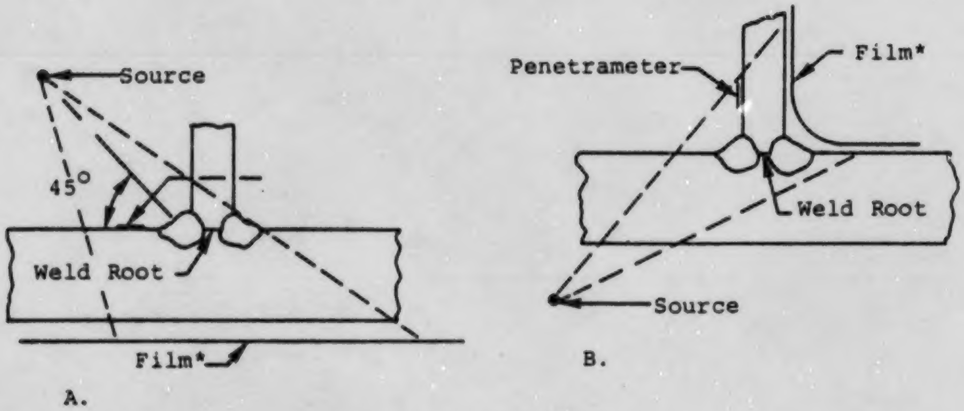
*Note: Film packed with 0.005" front and 0.010" back lead screens.

Figure 26-6-15 Flat Welded Plates

Welded tee joints such as those shown in Figure 26-6-16, present different problems. The weld root is the area most likely to contain defects, yet no convenient location for the film can be found that will give good weld room image resolution. Either arrangement A or B can be used. It should be noted, however, that the object (weld zone) - film distance is quite large in sketch A, and that a very long source-to-film distance is required to produce good resolution. (Please refer to the next page for Figure 26-6-16.)

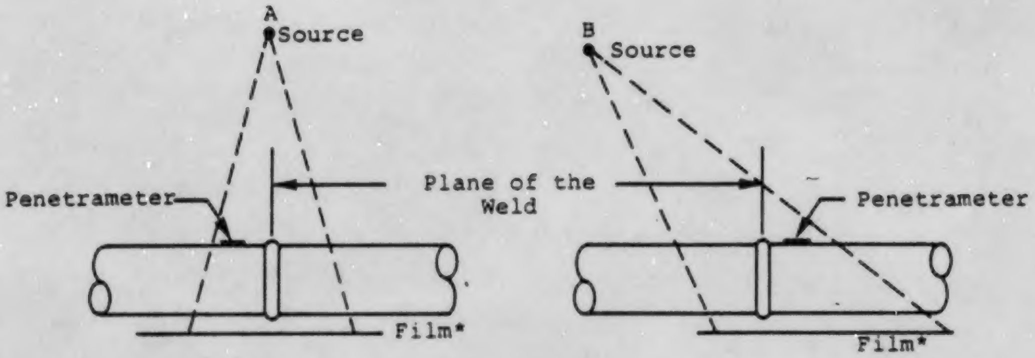
Weld Joints of Pipe

Small pipe welds, i.e., 1-1/2" or less, can usually be radiographed with the entire weld exposed on a single film, as shown in Figure 26-6-17. With the source a location "A", however, the images of both front and back pipes walls are projected onto the same film area, where it would not be possible to determine which wall contained a defect


Source
45°
Weld Root
Film*
A.
Penetrameter
Film*
Weld Root
Source
B.

*Note: Film packed with 0.005" front and 0.010" back lead screens.

Figure 26-6-16 Welded Tee Joint on Plate


A
Source
B
Source
Plane of the Weld
Penetrameter
Penetrameter
Film*
Film*

*Note: Film packed with 0.005" front and 0.010" back lead screens.

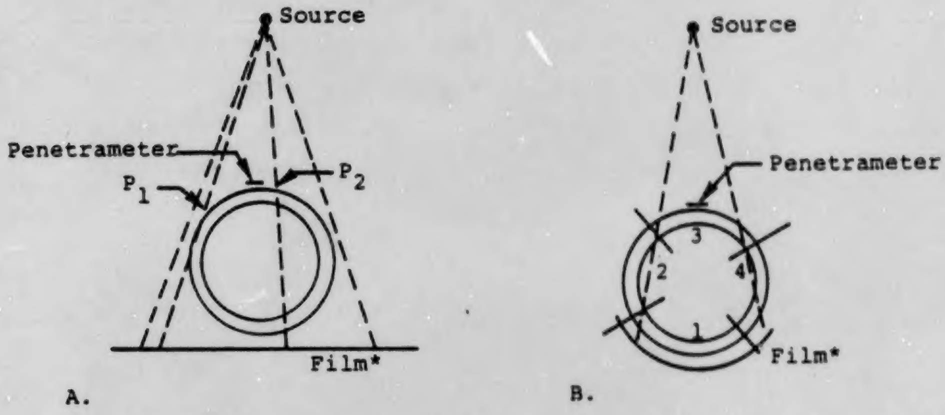
Figure 26-6-17 Large Pipe Welds (Profile)

if one were present. A better arrangement is to off set the source from the plane of the weld, such as at location B, thereby producing an elliptical weld image which will reveal the location of existing weld discontinuities.

Large pipe welds, i.e., over 1-1/2", can seldom be radiographed successfully with only one exposure. One problem encountered by the radiographer is that it is difficult to determine the effective length of the radiation path through the specimen for calculating exposure time. Sketch A in Figure 26-6-18 illustrates that the material thickness along radiation path P_1 is much greater than at path P_2. The resulting radiograph will be much darker in area P_2 than at P_1; i.e., when one area of the radiograph is exposed to the required density of other areas will be either too light or too dark. Acceptable radiographs of the pipe can be obtained by dividing the weld circumference into 3 or 4 segments, as shown in sketch B of Figure 26-6-18, and radiographing each with a separate exposure. If the pipe has diameter 12 inches or greater and its interior is accessible, it can usually be radiographed with one exposure by wrapping the film around the exterior or circumference and placing the radiation source internally at the center. This technique is also used in pressure vessel radiography.

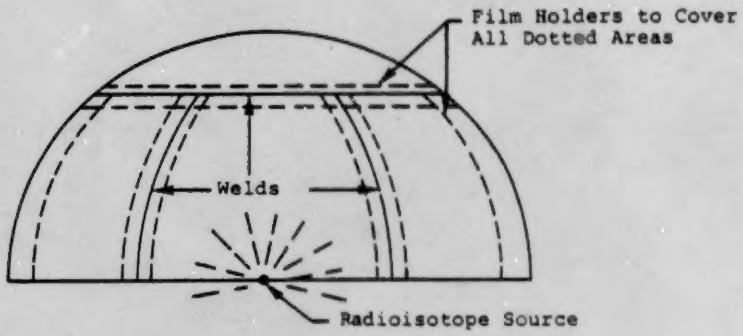
Hemispherical "Orange Peel" Head

An efficient method of radiographing the welds on spherical and hemispherical pressure vessels is illustrated in Figure 26-6-19. Film holders are placed over the weld areas as shown, the source placed at the geometric center, and all films exposed simultaneously with the 360° beam.


Source
Penetrameter
P_1
P_2
Film*
A.
Source
Penetrameter
3
2
4
1
Film*
B.

*Note: Film packed with 0.005" front and 0.010" back lead screens.

Figure 26-6-18 Large Pipe Welds


Film Holders to Cover All Dotted Areas
Welds
Radioisotope Source

Notes:

1. Penetrameters placed on shell interior, adjacent to welds.
2. Film holders placed on shell exterior.
3. Film packed with front and back lead screens.

Figure 26-6-19 Hemispherical "Orange Peel" Head

Panoramic Exposure

When groups or large numbers of small, similar parts are to be radiographed, a panoramic exposure arrangement may be used as shown in Figure 26-6-20. The parts, with penetrameters and film packs, are arranged in a circular array around the source, and all exposed simultaneously.

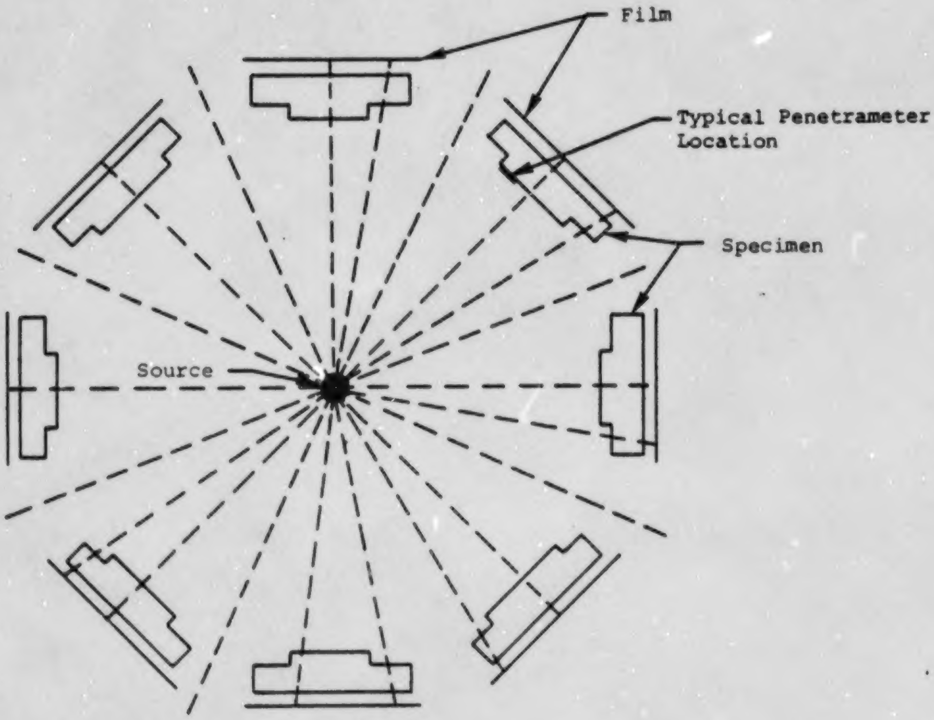

Film
Typical Penetrameter Location
Specimen
Source

Figure 26-6-20 Panoramic Exposure Arrangement

Multiple Exposure or Multiple Film

On specimens with large subject contrast (or large thickness differences) it may not be possible to produce a radiograph with acceptable density in all areas, with one exposure on one film. This problem may be resolved by using one of the following techniques:

1. Multiple exposures, as illustrated in Figure 26-6-21, using the same film may be made, with the source and the film for each arrangement adjusted to produce the optimum exposure and radiograph for each particular section of the specimen.

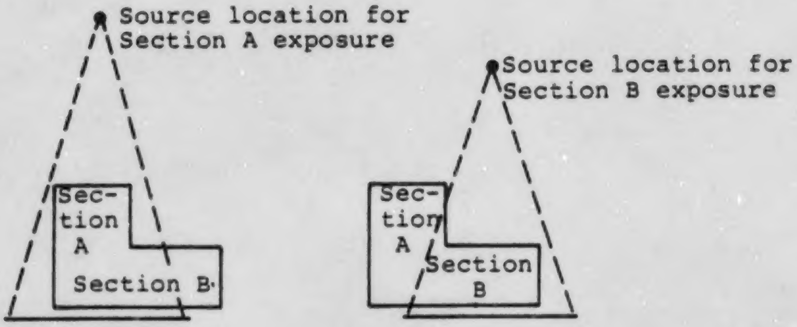

Source location for Section A exposure
Sec-tion A
Section B
Source location for Section B exposure
Sec-tion A
Section B

Figure 26-6-21 Multiple Exposure Technique

2. Multiple films (usually 2) of the same type may be loaded into the same film pack and exposed simultaneously, as shown in Figure 26-6-22. When viewing and reading the finished radiograph, the two films are superimposed and read together for the area representing the thick section of the specimen, and the films are read individually for the area representing the thin section (the radiograph of a thin section will be darker (denser) than a radiograph produced with the same exposure of a thick section).

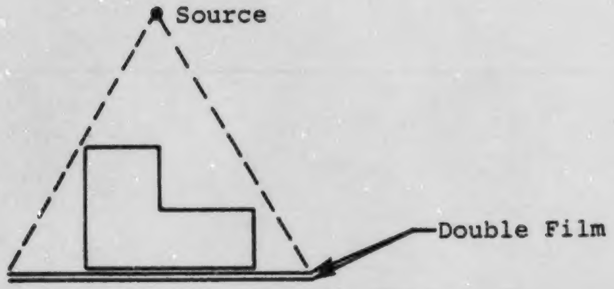


Figure 26-6-22 Multiple Film (Same Type) Technique

3. Multiple films (usually 2) of different speeds or sensitivities may be loaded into the same film pack and exposed simultaneously as shown in Figure 26-6-23. The exposure can be adjusted so that the slow film produces a radiograph of acceptable density for the thin section of the specimen, and the fast film produces a radiograph of acceptable density for the thick section of the specimen.

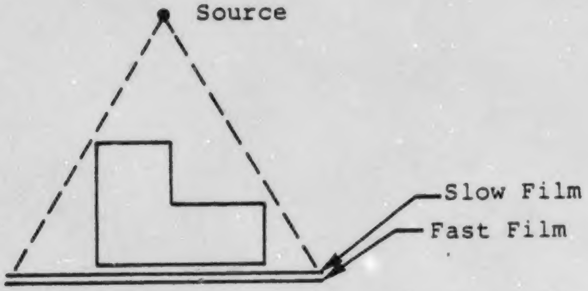


Figure 26-6-23 Multiple Film (Slow/Fast) Technique

FILM PROCESSING AND HANDLING

The film processing operations of development, stop bath, fixation, washing and drying are covered in Module 26-5, "Fundamentals of Radiography", along with the descriptions of typical equipment used.

A primary consideration in film handling and processing operations is cleanliness. The processing area or room and all accessories and equipment must be kept scrupulously clean to preclude damage to film or contamination of processing chemicals.

Careful handling by the radiographer will minimize such physical film damage as scratches, crimp marks, and pressure marks, all of which can occur during the loading and unloading of film holders, film cassettes, and automatic processing equipment.

UNSATISFACTORY RADIOGRAPHS: CAUSES AND CORRECTIONS

Errors in technique or the mishandling of radiographic materials may result in unsatisfactory radiographs. Scratches, marks or other blemishes on the film, and images on the film resulting from foreign material, static electricity or sources other than the specimens may be viewed and interpreted as apparent discontinuities in the specimen. These apparent discontinuities are known as artifacts and must be identified as irrelevant indications during the film reading and interpretation phase of the examination. Some of the common quality defects and artifacts found in finished radiographs are listed in Table 1, with their probable causes and suggested corrective actions. In all cases, and radiographer should try to identify the cause and prevent a recurrence.

TABLE 1

IMAGE QUALITY DEFECTS AND ARTIFACTS IN FINISHED RADIOGRAPHS WITH PROBABLE CAUSES AND CORRECTIVE ACTIONS

IMAGE QUALITY OR ARTIFACT	PROBABLE CAUSE	CORRECTIVE ACTION
Density too high	Overexposure	View with higher intensity light Check exposure (time and radiation intensity); if as specified, reduce exposure 30% or more.
	Overdevelopment	Reduce development time, or reduce developer temperature.
	Fog	See "Fog".
Density too low	Underexposure	Check exposure (time and radiation intensity); if as specified, increase exposure 40% or more.
	Underdevelopment	Increase development time or developer temperature. Replace weak (depleated) developer.
	Material between screen and film	Remove material.
Contrast too high	High subject contrast	Increase tube voltage.
	High film contrast	Use a film with lower contrast characteristics.
Contrast too low	Low subject contrast	Reduce tube voltage
	Low film contrast	Use a film with higher contrast characteristics.
	Underdevelopment	Increase development time or developer temperature. Replace weak (depleated) developer.
Poor definition	Test-piece-to-film distance too long	If possible, decrease test-piece-to-film distance; if not, increase source-to-film distance.
	Source-to-film distance too short	Increase source-to-film distance.
	Focal spot (or gamma-ray source) too large	Use smaller source or increase source-to-film distance. (Continued)

TABLE 1 (Continued)

IMAGE QUALITY DEFECTS AND ARTIFACTS IN FINISHED RADIOGRAPHS
WITH PROBABLE CAUSES AND CORRECTIVE ACTIONS

IMAGE QUALITY OR ARTIFACT	PROBABLE CAUSE	CORRECTIVE ACTION
Poor definition (Continued)	Screens and film not in close contact	Ensure intimate contact between screens and film.
	Film graininess too coarse	Use finer-grain film.
Fog	Light leaks in darkroom	With darkroom unlighted, turn on all lights in adjoining rooms; seal any light leaks.
	Exposure to safelight	Reduce safelight wattage. Use proper safelight filters.
	Stored film inadequately protected from radiation	Attach strip of lead to loaded film holder and place in film-storage area. (Continued)
Fog (Continued)		Develop test film after 2 to 3 weeks; if image of strip is evident, improve radiation shielding in storage area.
	Film exposed to heat, humidity, fo gases	Store film in a cool, dry place not subject to gases or vapors.
	Overdevelopment	Reduce development time, or reduce developer temperature.
	Developer contaminated	Replace developer.
	Exposure during processing	Do not inspect film during processing until fixing is completed.
Finely mottled fog	Stale film	Use fresh film.
Fog on edge of corner	Defective cassette	Discard cassette.
Yellow stain	Depleted developer	Replace developer solution.

(Continued)

TABLE 1 (Continued)

IMAGE QUALITY DEFECTS AND ARTIFACTS IN FINISHED RADIOGRAPHS WITH PROBABLE CAUSES AND CORRECTIVE ACTIONS

IMAGE QUALITY OR ARTIFACT	PROBABLE CAUSE	CORRECTIVE ACTION	IMAGE QUALITY OR ARTIFACT	PROBABLE CAUSE	CORRECTIVE ACTION
Yellow stain (Continued)	Failure to use stop bath or to rinse	Use stop bath, or rinse thoroughly between developing and fixing.	Dark fingerprints	Touching undeveloped film with chemically contaminated fingers	Wash hands thoroughly and dry, or use clean, dry rubber gloves.
	Depleted fixer	Replace fixer solution.	Light fingerprints	Touching undeveloped film with oily or greasy fingers	Wash hands thoroughly and dry, or use clean, dry rubber gloves.
Dark circular marks	Film spashed with developer prior to immersion	Immerse film in developer with care.	Dark spots or streaks	Developer contaminated with metallic salts	Replace developer solution.
Dark spots or marble-like areas	Insufficient fixing	Use fresh fixer solution and proper fixing time.	Crescent-shape light areas	Faulty film handling	Keep film flat during handling. Use only clean, dry film hangers.
Dark branched lines and spots	Static discharge	Unwrap film carefully. Do not rub films together. Avoid clothing productive of static electricity.	Light circular patches	Air bubbles on film during development	Agitate immediately upon immersion of film in developer.

TABLE 1 (Continued)

IMAGE QUALITY DEFECTS AND ARTIFACTS IN FINISHED RADIOGRAPHS
WITH PROBABLE CAUSES AND CORRECTIVE ACTIONS

IMAGE QUALITY OR ARTIFACT	PROBABLE CAUSE	CORRECTIVE ACTION
Circular or drop shape light patches	Water or fixer splashed on film before development	Avoid splashing film with water or fixer solution
Light spots or areas	Dust or lint between screens and film	Keep screens clean.
Sharply outlined light or dark areas	Nonuniform development	Agitate film during development.
Reticulation (leather-grain appearance)	Temperature gradients in processing solutions	Maintain all solutions at uniform, constant temperature.
Frilling (loosening of emulsion from film base)	Fixer solution too warm	Maintain correct temperature of the fixing solution
	Fixer solution depleted	Replace fixer solution.
White scum	Improperly mixed fixer solution (mixed too warm, too rapidly	Replace fixer, properly mixed.
	Fixer solution contaminated with developer	Replace fixer.

EXERCISES

Due to the special safety precautions which must be exercised in using radiographic test equipment laboratory exercises using this equipment are not suggested for this module. However, a field trip to either a manufacturing site, nuclear power plant or construction site employing radiography is suggested. Therefore, to reinforce the concepts presented in this module the following exercises are suggested.

1. Visit a facility or construction site and observe the use of radiographic non-destructive examination techniques in action. Prepare a report as outlined in the Procedures section of this module.

2. Using Figure 26-6-1 perform the following exercise: For radiography steel specimens using lead screens in the film packs, determine the x-ray tube voltage required for a steel thickness of:
   a. 2 inches ______________
   b. 4½ inches _______________

3. Using Figure 26-6-3 perform the following exercise: Determine which radiation sources shown in Figure 26-6-3 are suitable for radiographing a 4½ inch thick steel specimen.

4. Explain how radiographic films are classified.

5. Explain the purpose(s) of loading lead screens into film packs.

6. Refer to Figure 26-6-7 in performing the following exercise:
Using the factors listed on the chart, calculate the steel equivalent thickness (S.E.T.) for the following specimens.

a. 3" Steel, 1000 KV X-Ray S.E.T. = ____________

b. 4" Copper, Co-60 S.E.T. = ____________

c. 6" 2024 Alum., Co-60 S.E.T. = ____________

7. Refer to Figure 26-6-8 in performing the following exercise:
Using the equivalent curve, determine the "A" factor for the following steel equivalent thickness values:

a. 1" with Ir-192 A = _________________

b. 2.5" with Ir-192 A = _________________

8. Calculate the minimum source-to-film distance for the following object:

Round Plate

13" diameter

1-1/2" thick

Min. Source-to-Film Distance _________________

9. Calculate the gamma ray exposure time for the following arrangement (factors are given):

F = 6.6

A = 40

D = 20 inches

S = 10 curies

T = __________ minutes

10. Calculate the x-ray exposure required for the following specimen and arrangement:

Specimen: Steel, 1" thick, 10" diagonal measure

X-Ray Machine: 160 KV maximum

Notes: (1) Use minimum "rule-of-thumb" source-to-film distance.

(2) Use chart, Figure 26-6-13 for reference.

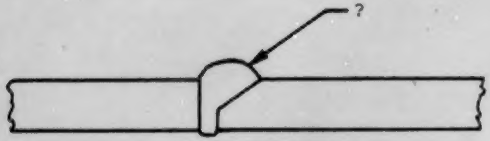
Exposure = ________________ ma - min

11. Explain why the weld root is a potential area to contain a defect and this area should be observed carefully during the radiographic testing.

12. Explain why it is good to have multiple exposures of pipe welds using the radiographic inspection technique.

13. Panoramic exposure arrangements are best for radiographing a number of similar or identical parts which can be arranged conveniently around a radiation source. Briefly explain why this is so.

14. Label the following sketch of butt weld plates.

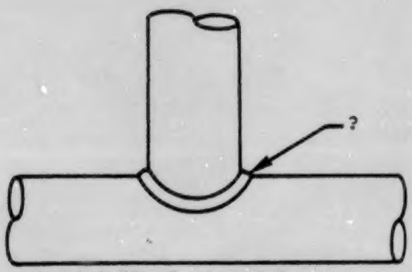


Butt Welded Plates

Label:

1. Source Location
2. Penetrameter Location
3. Film Location

15. Label the following sketch of a weld "Tee" pipe joint.



Welded "Tee" Pipe Joint

Label:

1. **Source Location(s)**
2. **Penetrameter Location(s)**
3. **Film Location(s)**
4. **Number of Exposures Required to Radiograph Entire Weld**

16. Unsatisfactory radiographs can and do occur in practice. Table 1 lists quality defects in finished radiographs. Using Table 1, list the effect on the film or image quality for the errors in technique listed as follows:

	Error	Effect on the Film or Image Quality
a.	Film overdevelopment	
b.	Static discharge	
c.	Overexposure	
d.	Underexposure	
e.	Exposure to scattered radiation	
f.	Depleted developer or fixer	
g.	Screens and film not in close contact	
h.	Handling undeveloped film with oily fingers	
i.	Extreme subject contrast	
j.	Nonuniform development	

MATERIALS

None.

PROCEDURES

1. Visit a facility or construction site which uses radiographic non-destructive examination techniques. Prepare a report which includes discussion of the following:
    a. Name and location of the site visited.
    b. Date of visit.
    c. Type(s) of radiographic NDE techniques employed.
    d. A sketch of a typical NDE setup using a radiographic technique.
    e. Type of records kept on the radiographic inspections performed.
    f. Description of the radiological safety measures used for the personnel employed at the site.

DATA TABLE

None.

REFERENCE MATERIALS

Eastman Kodak Company. Radiograhy in Modern Industry, 1969

McGonnagle, Warren J., Nondestructive Testing, New York: McGraw Hill Book Company

Metals Handbook, Volume 11, Nondestructive Inspection and Quality Control, American Society for Metals

McMaster, Robert C. (ed.) Nondestructive Testing Handbook, New York: The Ronald Press Company

Overman Ralph T., Basic Concepts of Nuclear Chemistry, New York: Reinhold Publishing Corporation

TEST

1. Using Figure 26-6-1, answer the following question:
   For radiography steel specimens using lead screens in the film packs, determine the x-ray tube voltage required for a steel thickness of:
   a. 2½ inches ______________
   b. 5 inches ______________

2. Using Figure 26-6-3, answer the following question:
   Determine which radiation sources shown in Figure 26-6-3 are suitable for radiographing a 3½ inch thick steel specimen.

3. Mark the following statements true of false:
   a. Higher x-ray tube voltages produce greater penetrating power. ______
   b. The gamma energy emitted by a radioisotope has a direct effect on the penetrating power. ______
   c. An Iridium-192 source has greater penetrating power than a similar size Cobalt-60 source. ______
   d. In x-radiography, film contrast is not influenced by tube kilovoltage ______
   e. Ir-192 cameras are usually much larger and heavier than Co-60 cameras. ______

4. Complete the following statements:
   a. Radiographic films are classified by ______________ and ______________.
   b. Industrial radiographic films are designed to produce ______________ and ______________ than medical type films.

5. Mark the following statements true or false.
   a. Bulk film sheets may be handled safely in daylight. ______
   b. Film sheets may be protected from static discharges by handling carefully and slowly. ______
   c. Lead screens are loaded into film packs when using intensification techniques. ______
   d. New film is only sensitive to x-radiation in storage after the sealed film carton has been opened. ______

6. Refer to Figure 26-6-7 in answering the following question:

   Using the factors listed on the chart, calculate the steel equivalent thickness (S.E.T.) for the following specimens.

   a. 1/2" Zirconium, 220 KV X-Ray S.E.T. = ________
   b. 2" 2024 Alum., Ir-192 S.E.T. = ________

7. Refer to Figure 26-6-8 in answering the following question.

   Using the equivalent curve, determine the "A" factor for the following steel equivalent thickness values:

   a. 2.2" with Co-60 "A" = ________________
   b. 4.5" with Co-60 "A" = ________________

8. Calculate the gamma ray exposure time for the following arrangement (factors are given):

   F = 14.9 D = 2.5 feet
   A = 50 S = 100,000 millicuries

   T = ____________ minutes

9. Use Figure 26-6-7 in answering the following questions:

a. What was the source activity at the time of calibration or chart preparation?

____

____

b. What is the source activity 54 days after calibration?

____

____

c. After how many days from the calibration date will the source activity decrease to 6.25 curies?

____

____

10. The use of lead screens with radiographic film produces which of the following effects:

a. increases photographic action, or film darkening ____

b. absorbs scattered radiation ____

c. intensifies primary radiation ____

d. all of the above ____

11. Calculate the minimum source-to-film distance for the following object:

Rectangular Plate

2" wide x 8" long (8.25" diagonal)

3" thick

Min. Source-to-Film Distance ____________________

12. Mark the following statements true or false:

a. In radiographing weld joints the area least likely to contain defects in the weld root. _____

b. All pipe welds should be exposed with a single film technique to keep the number of stored films to a minimum. _____

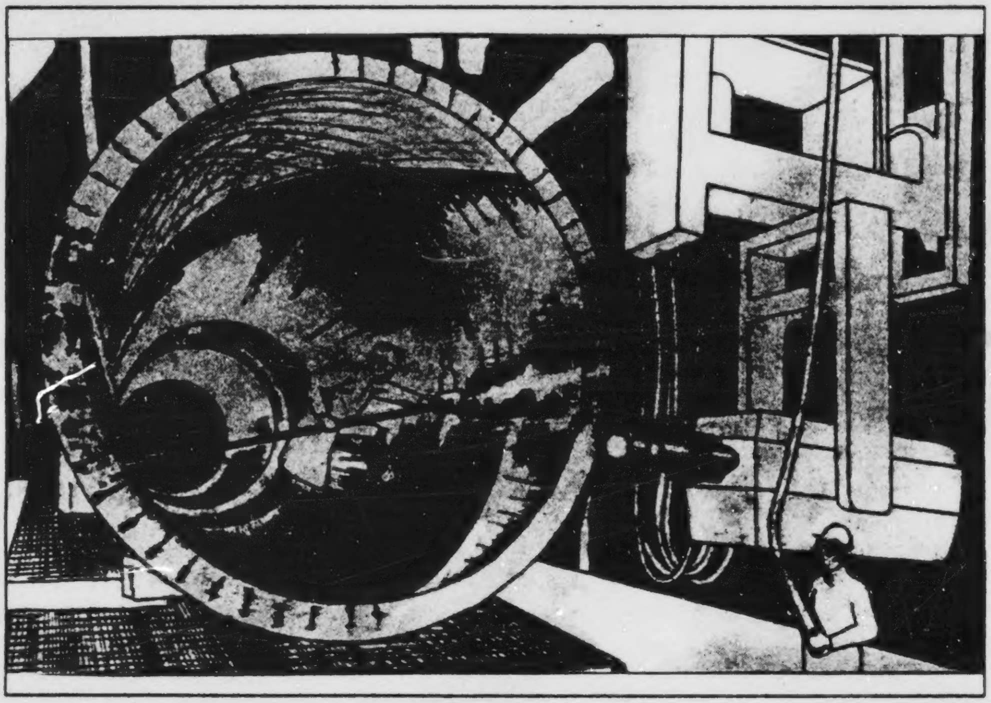
c. Panoramic exposure arrangements are best _____ for radiographing a number of similar or identical parts which can be arranged conveniently around a radiation source.

d. Multiple film techniques are frequently used _____ on welded flat plates.

NUCLEAR TECHNOLOGY

MODULE 26 - 7

RADIOGRAPHIC SPECIFICATIONS AND CODE REQUIREMENTS



COURSE 26: NONDESTRUCTIVE EXAMINATION (NDE)

CORD

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

4800 LAKEWOOD DRIVE WACO, TEXAS

COURSE 26 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES I

MODULE 26-1	Visual Tests
MODULE 26-2	Leak Tests
MODULE 26-3	Hydrostatic Tests
MODULE 26-4	Liquid Penetrant
MODULE 26-5	Fundamentals of Radiography
MODULE 26-6	Radiograph Inspection
⇨ MODULE 26-7	Radiographic Specifications and Code Requirements

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INTRODUCTION

Radiography is used to detect features of a component or assembly that exhibit a difference in thickness or density as compared to surrounding material, and to provide a photographic record of the inspection technique and results.

An acceptable radiograph is one which has a representative image of the specimen, has a fully distinguishable penetrameter image, exhibits suitable radiographic arrangement and techniques, and exhibits precision and uniformity of film processing. Modules 25-5 and 25-6 cover these characteristics, and are prerequisite to this module.

The finished radiograph becomes a valuable document only when evaluated by a qualified film interpreter. The film interpreter must examine the radiograph on an appropriate illuminator or film viewer, determine the acceptability of the radiograph procedure, analyze the nature and extent of any abnormal conditions or discontinuities observed in the specimen image, evaluate the findings of the examination by comparison to standards or specifications, and report the inspection results accurately.

The nondestructive testing inspector who normally performs film reading and interpretation must possess certain personal qualifications. These requirements are included in personnel standards published by the American Society for Nondestructive Testing, government agencies and many private manufacturers. Usually, a minimum level of visual acuity, minimum standards of education and training, and demonstrated proficiency are required of all interpreters of radiographs.

The QA/QC technician may not be required or qualified to perform the reading and interpretation of radiographs, but he should be familiar with all aspects of the activity and the applicable codes and specifications. The QA/QC technician frequently monitors film reading and interpretation, verfies conformance to code requirements and specifications, reviews test reports, and audits film interpreters and their work.

MODULE PREREQUISITES

The student/trainee must have completed modules 26-5 and 26-6.

OBJECTIVES

To satisfactorily complete this module, the trainee shall:

1. Demonstrate a knowledge of radiographic specification, code requirements and fundamentals of film interpretation by responding correctly to written exercises, which are similar to the questions included in the American Society for Nondestructive Testing SNT-TC-IA Level II certification written test.
2. Demonstrate a knowledge of discontinuities in materials by responding correctly to written questions about welds, castings and other commonly radiographed materials.
3. Demonstrate a knowledge of ASME and ASTM radiographic specifications and code requirements by completing exercises comparing specimen sketches and descriptions

to the standards illustrated and/or described in this text, and determining the acceptability of each specimen.

4. Demonstrate a knowledge of radiographic film interpretation and evaluation techniques by responding to related written questions.

DISCONTINUITIES IN MATERIALS

In addition to an understanding of the principles of radiography, the successful interpretation of radiographs requires a knowledge of the materials being tested so that the images of discontinuities observed may be related to the serviceability of the specimen.

The term discontinuity refers generally to any kind of flow, defect, fault or lack of continuity in a material that is required to be continuous throughout a given volume. Some general types of discontinuities are summarized:

- Cracks and Breaks - A "crack" is a defect in which the discontinuity has a relatively large cross-section in one direction and a small or negligible cross-section when viewed in a direction perpendicular to the first. A "break" is a crack of such a size or location that it may cause the object to separate into two parts.

  Cracks assume a variety of forms. They may have branches, parallel cracks and changes of direction. In general the cause of a crack is a stress perpendicular to the plane of the crack. Stresses may be caused by heating, cooling, cold working and deforming of metal. "Hot tears" may occur in castings when the mold interferes with free contraction of the casting.

  "Crazy pattern" can be produced when the surface of a piece of metal is made very hot in a relatively small area. Grinding, some types of welding operations, and some flame-hardening processes may cause this kind of crack.

- Holes - Gas holes, cavities, holes or air locks are internal defects or voids where it is expected to find solid material. Many such discontinuities cannot be seen from the surface and radiography or other nondestructive testing methods must be used to detect them.

  "Porosity" is a discontinuity in the form of a collection of small holes or voids in a material.
- Lack of Fusion - In the welding of materials, the failure of the weld metal to fuse properly with the base metal is termed "lack of fusion". In castings, lack of fusion occurs where two independent streams of molten metal meet or where a stream splits and meets again with a slightly lower temperature, too low to allow the two streams to fuse together. This phenomenon is also referred to as a "cold shut".

  In the casting process, chaplets are pieces of metal used to position cores in molds. When the molten metal is introduced in the mold, the chaplets are supposed to fuse and become a part of the casting. In practice, they seldom fuse completely, and are referred to as "unfused chaplets" when this condition occurs.
- Inclusions - Inclusions are foreign materials, metallic or non-metallic, which are entrapped in cast material or weld metal. In castings, inclusions may consist of slag, sand or parts of the mold surface that come off in the molten metal. Weld metal may include materials such as slag, silvers of tungsten electrodes, or particles resulting from improper cleaning between passages.

- Surface Irregularities - Surface irregularities are conditions such as surface pits, formed by escaping gas bubbles, excess weld metal, or weld "undercut" which is a reduction in base metal thickness at the point where the last weld pass fused to the surface.

  Surface irregularities may or may not be a defect that renders the material unserviceable. The surfaces of parts to be radiographed should first be visually examined to identify any surface irregularities so that they and internal discontinuities may be distinguished on the radiograph.

RADIOGRAPHS OF WELDS

One of the largest uses of industrial radiography is for examining welds. Defects in welds usually consist of either a void in the weld metal or an inclusion in the surrounding weld metal. The more common weld defects are described below, along with their cause and effect, and appearance on the radiograph:

- Gas Holes and Porosity - Gas may be formed in fusion welding because of poor control of arc current, technique used, electrodes used, and quality of base metal. The term "porosity" is used to describe gas inclusion that occur as spherical cavities in the weld metal. Gas inclusions may also occur as a tube-like cavity sometimes referred to as a "wormhole". Porosity may occur as single cavities, in clusters of cavities, or randomly scattered cavities. Linear porosity may also occur along with incomplete penetration and is a series of cavities distributed along a line that runs lengthwise with the weld.

- Weld Slag Inclusions - Slags are usually oxides produced by arc welding. They serve to help take impurities from the molten metal and to form an insulating layer over the weld to control cooling rates. Some slag may be trapped in the weld metal if it fails to remain molten long enough for the slag to rise to the surface. In welding requiring multiple passes, slag may be left on previous passes unless properly cleaned. Slag inclusions may be located along the edges of the weld metal deposits and run in a line along the length of the weld.

  Since the oxides making up slags are usually of a lower density than iron, they show up as dark, irregular shapes on radiographs. Slag inclusions can occur singly, in clusters, or scattered randomly throughout a weld. They may also occur in a linear distribution. The images may have sharp, pointed ends and may be of variable density.

  Slag lines appear along the edge of a weld as an irregular or continuous dark line on the radiograph. These are usually caused by insufficient cleaning between weld passes. Voids left between passes by irregular deposits of metal cause lines that have a similar radiographic appearance.

- Cracks or Breaks - Cracks in welds are usually produced by internal stresses caused by shrinkage of the cooling weld. Cracks may be along the weld seam or they may be across the weld seam. Cracks are generally wavy or zig-zag lines and may have fine hairline cracks branching off from the main crack.

The radiographic image of a crack defect is a narrow line that is usually irregular. If the plane is not exactly in line with the radiation beam, a faint, dark linear shadow may result. In this case, additional radiographs should be taken at other angles.

- Lack of Penetration - Lack of penetration is the failure of the root pass to fuse properly with the base metal at the root, and occurs at the root opening at the bottom of the welding groove or at the center of the weld for two-sided welding. Root openings are used to permit peentration of fusion to the bottom of the weld opening or groove. Often tack welds are used to prevent movement of pieces being welded, followed by one or more passes made with the beads being laid over each other until the groove is filled.

If the root opening is too small for the weld rod and the current being used, incomplete penetration may result. Sometimes poor beveling or preparation of the weld groove can cause voids at the root area of the weld. Where possible, a cover pass on the back side of the weld may fill such a void.

The radiographic image of such a void appears as a straight, dark line in the center of the weld. The width may vary from a thin, sharp line to a broad, diffused line. Slag inclusions and gas holes may be found in the connection with a lack of penetration void. These may cause enlargement of the primary dark line, or cause it to be accompanied by a sort of dotted line. Slag inclusions may cause the primary line to appear broad and irregular.

Sometimes, lack of penetration may show on a radiograph as a very narrow dark line. The narrowness may be due to a drawing together of the plates being welded and the lack of penetration may be very severe.

- Lack of Fusion - Lack of fusion occurs as a result of lack of heat or poor cleaning of the fusion face of a weld bevel. The weld metal may not fuse to the parent metal, and remains separated by a thin layer of oxide, resulting in a discontinuity along the wall of the bevel.

  A radiograph of a lack of fusion shows a very thin, straight, dark line parallel to and on one side of the weld image. A lack of fusion line is usually straight on one side and irregular on the other.

- Tungsten Inclusions - Tungsten particles or splinters may be generated by the contact of the tungsten electrode used in arc welding, and become trapped in the metal that is deposited. No fusion of the tungsten will occur due to its high melting point. Tungsten is a dense, high atomic weight material with higher radiation absorption than iron, appearing as light marks on a radiograph.

  Tungsten inclusions may appear as single light spots, or as clusters of small light spots, and usually are irregular in shape.

- External Discontinuities - Various kinds of surface irregularities may cause density variations on a radiograph.

  A common surface discontinuity is undercutting, which is caused by melting of the upper edge of the beveled weld face. When insufficient weld metal is deposited to fill the groove, the base metal may be reduced in thickness at the point of fusion on the edge of the weld bead, resulting in the formation of a radiographic image which shows a dark line of varying width and density. The darkness or density of the line indicates the depth of the undercut.

In the multipass welds on horizontal positions, a rough top surface frequently results with longitudinal grooves paralleling the weld seam. On the radiograph, these grooves appear as dark lines with diffused edges, and should not be mistaken for slag lines which are narrow and sharply defined. These dark lines are seldom straight, but are parallel to the weld seam.

Molten metal sometimes flows through the root of the weld groove and forms hanging drops of metal, or "grapes", on the backside of the weld. This condition shows a round, light spots on the radiograph.

In overhead welding, a concavity at the root of the weld may be formed. This condition means less weld metal at the root, and will show on the radiograph as a dark, broad line at the center of the weld without sharply defined boundaries.

Weld grooves not completely filled with weld metal appear as dark lines on the radiograph. If the lack of fill occurs at the bevel, the dark line will be located on one edge of the weld image and will have a sharp border on one side and an irregular border on the other side. If the incomplete fill occurs in the center of the weld, the dark line will be rather wide and have diffused borders.

Weld grooves may be overfilled due to an excessive number of passes or an inadequate arc current. The overfill is referred to as "weld reinforcement". If the reinforcement is too high, the weld radiograph will show a lighter line down the weld seam. There will be a sharp change in image density where the reinforcement meets the base metal.

Weld excess metal is deposited on the final pass, the excess metal may overlap the base metal with a lack of fusion at the edge. A sharp change in image density between reinforcement and base metal will show in the radiograph, with an irregular edge image of the reinforcement.

Reinforcement thickness may be reduced on a cover pass at the end of a bead laid with an electrode which is to be changed. Increased thickness may occur at the point where the new electrode is started. The extra reinforcement forms a crescent shape with its convex side nearest the reduced reinforcement area left by the first electrode. The radiograph shows a crescent shaped image of less density because of extra metal.

In pipe welding, it is often impossible to make a cover pass at the root of the weld. A backing ring is frequently inserted before welding and left inside the pipe. This ring is partially fused to the weld metal on the root pass, and produces a well-defined image on the radiograph as a light band. The weld reinforcement shows up as a still lighter line across this band. Many of the usual weld discontinuities may still occur where backing rings are used. Slag entrapment may cause concavity at the root during the root pass, and lack of penetration also may occur.

RADIOGRAPHS OF CASTINGS

Another major use of industrial radiography is for examining ferrous and nonferrous castings. A casting is a piece of metal formed in a mold which is a shaped cavity prepared to receive molten metal. Molds of many types and shapes are used to cast such parts as pump casings and impellers, valve bodies and parts, motor housings and frames, pipe, and pipe fittings.

Radiography serves the foundry or casting industry in two ways: (1) it is used to inspect casting to control quality of production, or to avoid service failures, and (2) it is used as an aid in casting design in the development of good foundry techniques related to chilling, gating systems, risering and venting.

The thoroughness with which a casting should be radiographed depends upon the design and use to which the casting will be put. Castings that must undergo high stresses and which may not have a high safety factor may require extensive radiographing. Castings not subjected to high stresses may require only a minimum of radiography necessary to detect the most severe defects.

Finished casting products, such as pumps, valves and pipe fittings are frequently radiographed during installation to verify their integrity and freedom from unacceptable discontinuities. Similar radiographic examinations may be performed during preventive maintenance, repair, or inservice inspection operations.

Some of the commonly found discontinuities in castings which appear on radiographs are listed below:

- Gas Holes - The entrapment of gas as molten metal cools and solidifies in a mold produces voids known as "gas holes." The gas may have been dissolved in the metal, it may arise from the mold, or it may have been trapped as the molten metal was "gated" into the mold. The holes may occur singly, in clusters, or randomly distributed throughout the casting. Gas holes appear on the radiograph as dark areas with smooth borders.

  In evaluating the effects of gas holes found by radiography, the end use of the casting should be considered. The part may be required to hold liquid or gas, as would a valve body or pump casing, or it may be highly stressed, as a motor frame. The effects of gas holes on its function, therefore, should be studied. The service requirements for the part should be known and used in the interpretation of radiographs showing defects or discontinuities such as gas holes.

  Generally, gas holes weaken a part. The amount of weakening is based on the size of the gas hole or holes in relation to the cross-section of the part in which they exist. Gas holes grouped closely may be considered as one larger hole. Gas holes may be aligned in such a way as to represent a "propagating" discontinuity. This is a serious defect which renders the part unacceptable, particularly if the part is subjected to repeated vibration or shock stresses.

- Porosity - A spongy or porous condition in a casting is known as "porosity". Two types of porosity have been identified: gas porosity and shrinkage porosity.

Gas porosity is caused by the release of gas from the cooling metal and from green sand molds. The inclusion of various kinds of impurities as well as high temperatures may also account for gas in a casting. Gas porosity appears as very small, round, dark spots on a radiograph, and may vary from very minute spots closely bunched to single large round spots.

Shrinkage porosity may occur as a result of improper cooling and shrinkage. If the risers cool and solidify prematurely, molten metal is not available to keep the mold cavity completely filled as the cooling process continues. Some or all of the casting then may have some shrink porosity, which appears as a dark, highly irregular-shaped image on the radiograph, easily distinguishable from gas porosity.

- Shrinkage Cavities - Shrinkage cavities are voids caused by an insufficient amount of molten metal in the mold when the casting cools, and are usually found along with shrink porosity. Early setting of the metal in the risers may cause a part of the casting to receive insufficient metal as the part sets. Shrinkage cavities appear on a radiograph as dark irregular-shaped spots which vary considerably in cross-sectional area depending upon the size of the casting.

  Shrinkage cavities and gas holes have a similar effect on the serviceability of castings. Shrinkage cavities are considered to be serious defects, as they are propagating types of discontinuities.
- Microshrink - A from of shrinkage encountered mostly in non-ferrous castings such as aluminum alloy or

especially magnesium. It occurs usually at discontinuities of section such as the intersection of a thin web with a heavy boss, rib or flange. It is more severe if the fillet radius is less than the thickness of the thinner element (web etc.) This shrinkage results usually from differential rates of cooling in the thin and heavy sections. It is usually of extremely small voids or grain separations, showing a faint but discernible irregular shadow on the film. It may occur as a shrink-strain (residual stress) only, which cannot be detected by x-rays, but only by destructive strength or impact testing. Unless there is evidence of ample gates or risers in such thin elements or documentation of proper stress relief, great care should be used in both x-ray and physical testing of such castings to rule out potentially unsafe microshrink and residual stress. The level of care required is of course related to the probability and consequences of failure in a particular casting.

- Inclusions - Foreign materials, such as sand, slag or oxide, entrapped in a casting are known as inclusions. Inclusions may or may not affect the serviceability of the casting, depending on the quantity and location within the casting. Inclusions may appear either as dark spots or light spots on the radiograph, depending upon the relative densities of the inclusion and the base metal.
- Misruns - A misrun is the term applied to a casting containing a void produced when molten metal failed to fill the mold completely. It may be a minor void which is externally apparent, or it may connect to a deeper cavity which is not apparent on the surface, but is visible on the radiograph. Misruns appear on radiographs as dark areas with well-defined borders.

- Cold Shuts - The unfused-condition that may result in a casting when two separate streams of molten metal fail to fuse together upon meeting is called a cold shut. This condition occurs with premature cooling and setting of the molten metal. Cold shuts appear as well-defined dark lines on a radiograph, but may be difficult to detect.
- Cracks - Cracks may be caused by stresses in cooling of the casting, incorrect design of the casting, or by rough handling of the mold. In most cases, a crack makes a casting unacceptable. On a radiograph, cracks appear as dark irregular, intermittent or continuous lines. Cracks are usually very irregular and may not align properly with the radiation beam to produce a distinct image. Exposures from several different locations may be necessary, therefore, to determine the extent of a crack or to even accurately locate one.
- Segregation - The constituent metals in certain alloys used for castings sometimes tend to separate in spots during cooling in the mold producing segregation. This condition will show on the radiograph as light and dark blotches.
- Surface Irregularities - The most common surface irregularities are surface pits and excess metal. The surfaces of a part should be studied carefully so that the interpreter can distinguish any irregularities from internal discontinuities.

  Surface pits usually appear on the radiograph as diffused dark spots with poorly defined borders, similar to the images of inclusions.

  Excess metal appears as light areas corresponding to the dimension of the excess metal.

RADIOGRAPHIC STANDARDS

In this section on standards, the following abbreviations will be used:

- ASME - American Society of Mechanical Engineers Boiler and Pressure Code
- ASTM - American Society of Testing and Materials Standards
- USAS - USA Standard Codes (Published by ASME)

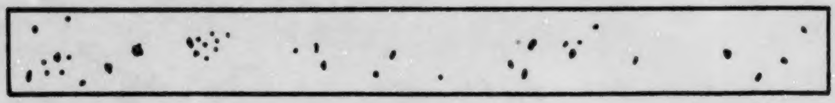
Industrial radiography is generally performed in accordance with specific radiographic codes and standards or manufacturer's specifications. The radiographer and the interpreter must be familiar with the applicable standards so that the required radiographic quality is attained, and that the proper judgement is made as to the acceptability of the material examined.

Most U.S. codes and specifications for radiographic inspection require that the sensitivity to a specific flaw size be indicated on each radiograph. Sensitivity is determined by placing a penetrameter (image - quality indicator) that is made of substantially the same material as the specimen directly on the specimen prior to each exposure. Usually, the penetrameters are placed on the side of the specimen nearest the source. Penetrameter thickness is usually specified to be 2% of the specimen thickness, although 1% and 4% penetrameter thickness also are common. ASTM and ASME plaque - type penetrameters are most commonly used types, and are discussed in greater detail in Module 26-5.

A typical standard for radiographic examination methods is setforth in ASME Code, Section V, Article 2, "Radiographic Examination". This standard defines such requirements as surface preparation, film selection, screens and processing, radiographic quality, radiographic density, scattered radiation control, material/film identification, radiation sources, radiographic image sharpness, selection and placement of penetrameters, procedure compliance, and evaluation of radiographs.

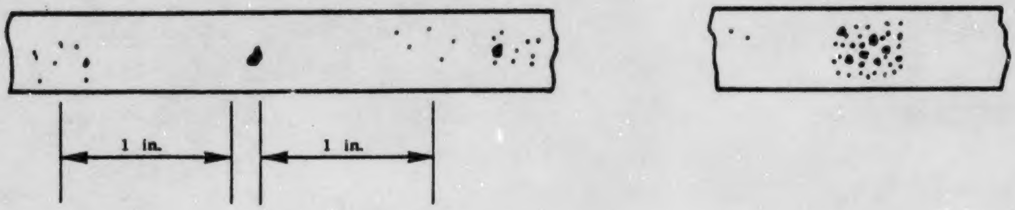
Other sections of the ASME Code provide specific acceptance criteria for applicable equipment and piping covered by the Code. As an example, the ASME Code, Section 1, Appendix A-250, provides Acceptance Standards for Radiographically Determined Porosity in Welds, as applicable to the fabrication of power boilers. This part of the Code defines relevent indications, aligned rounded indications, and spacing, and has charts of typical indications (discontinuities) illustrating maximum acceptable assorted, randomly dispersed, and clustered rounded indications for different weld thickness greater than 1/8 inch. These charts are known as porosity charts and are illustrated in Figure 26-7-1 through 26-7-6 , which were extracted from the Code. Other sections of the ASME Code, applicable to nuclear power plant components and to pressure vessels have similar radiographic examination acceptance standards and charts.

Another type of acceptance standard is the comparison or reference radiograph. Comparison radiographs have been prepared by the ASTM along with other reference materials for controlling quality in radiographic testing and for providing standard acceptance criteria for steel castings, aluminum and magnesium castings, and steel welds. For example, the materials prepared for steel castings include sets of radiographic negatives of defects encountered in carbon-steel and alloy-steel castings. They are intended to help in the classification of defects revealed by radiographic inspection. A set of plates is available for x-ray radiographic inspection, and another for gamma-ray and million-volt x-ray radiographic inspection.



RANDON ROUNDED INDICATIONS

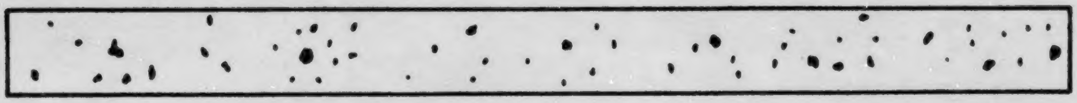
Typical concentration and size permitted in any 6 in. length of weld.



ISOLATED INDICATION
Maximum size per Table 1

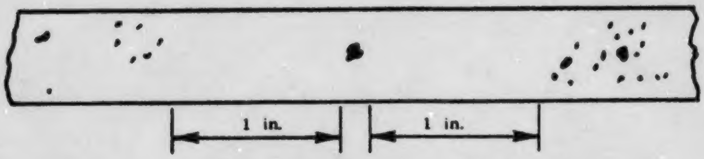
CLUSTER

Figure 26-7-1 ASME Porosity Chart
Chart for 1/8 In. to 1/4 In., Inclusive



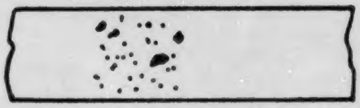
RANDOM ROUNDED INDICATIONS

Typical concentrationand size permitted in any 6 in. length of weld.



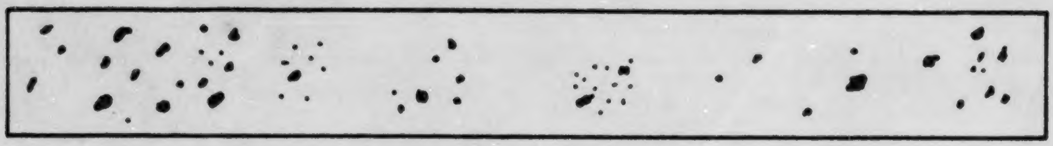
ISOLATED INDICATION

Maximum size per Table 1



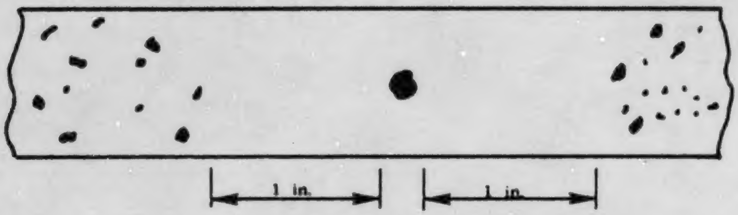
CLUSTER

Figure 26-7-2 ASME Porosity Chart
Chart for Over 1/4 In. to 3/8 In., Inclusive



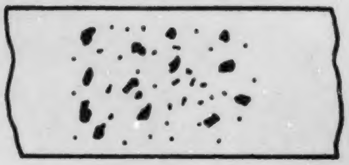
RANDOM ROUNDED INDICATIONS

Typical concentration and size permitted in any 6 in. length of weld.



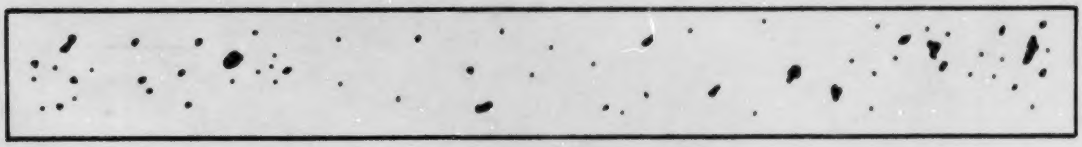
ISOLATED INDICATION

Maximum size per Table 1



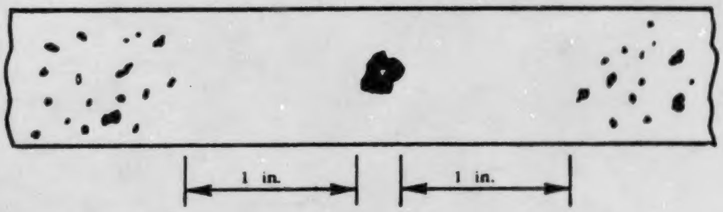
CLUSTER

Figure 26-7-3 ASME Porosity Chart
Chart for Over 3/8 In. to 3/4 In., Inclusive



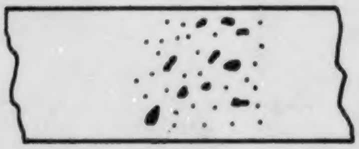
RANDOM ROUNDED INDICATIONS

Typical concentration and size permitted in any 6 in. length of weld.



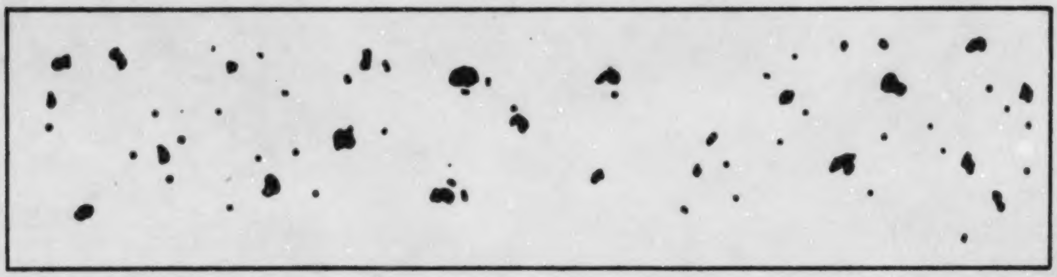
ISOLATED INDICATION

Maximum size per Table 1



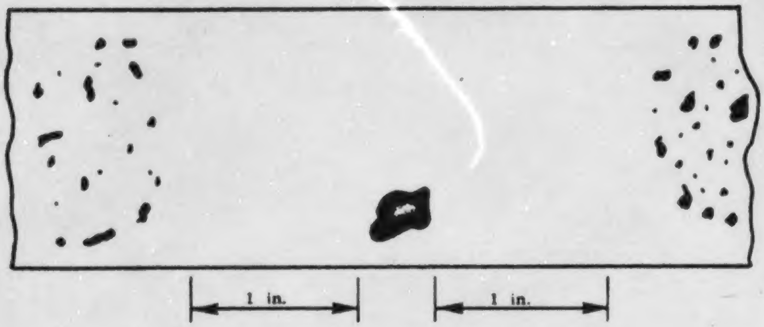
CLUSTER

Figure 26-7-4 ASME Porosity Chart
Chart For Over 3/4 In. to 2 In., Inclusive



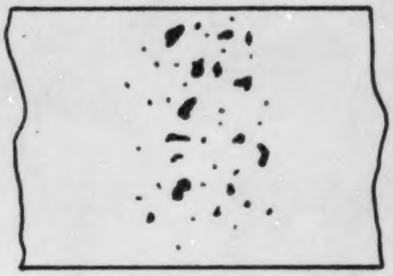
RANDOM ROUNDNESS INDICATIONS

Typical concentration of size permitted in any 6 in. length of weld.



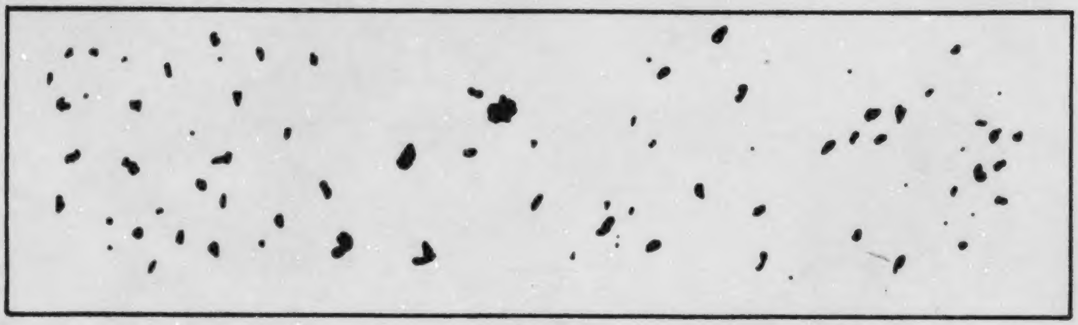
ISOLATED INDICATION

Maximum size per Table 1



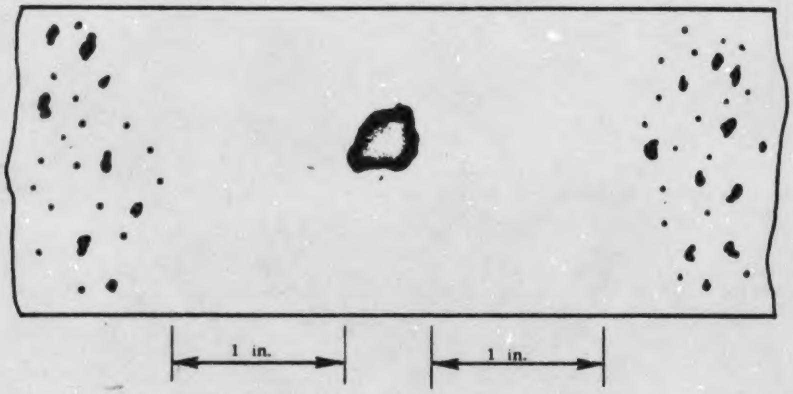
CLUSTER

Figure 26-7-5 ASME Porosity Chart
Chart For Over 2 In. To 4 In., Inclusive



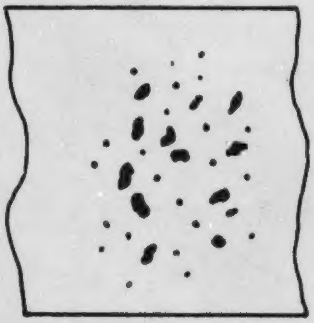
RANDOM ROUNDNESS INDICATIONS

Typical concentration and size permitted in any 6 in. length of weld.



ISOLATED INDICATION

Maximum size per Table 1



CLUSTER

Figure 26-7-6 ASME Porosity Chart
Chart for Over 4 In.

TABLE 1
(Examples Only)

Thickness t, in.	Maximum Size of Acceptable Rounded Indication, in.		Maximum Size of Nonrevelant Indication, in.
	Random	Isolated	
Less than 1/8	1/4t	1/3t	1/10t
1/8	0.031	0.042	0.015
3/16	0.047	0.063	0.015
1/4	0.063	0.083	0.015
5/16	0.078	0.104	0.031
3/8	0.091	0.125	0.031
7/16	0.109	0.146	0.031
1/2	0.125	0.168	0.031
9/16	0.142	0.188	0.031
5/8	0.156	0.210	0.031
11/16	0.156	0.230	0.031
3/4 to 2 incl.	0.156	0.250	0.031
Over 2	0.156	0.375	0.063

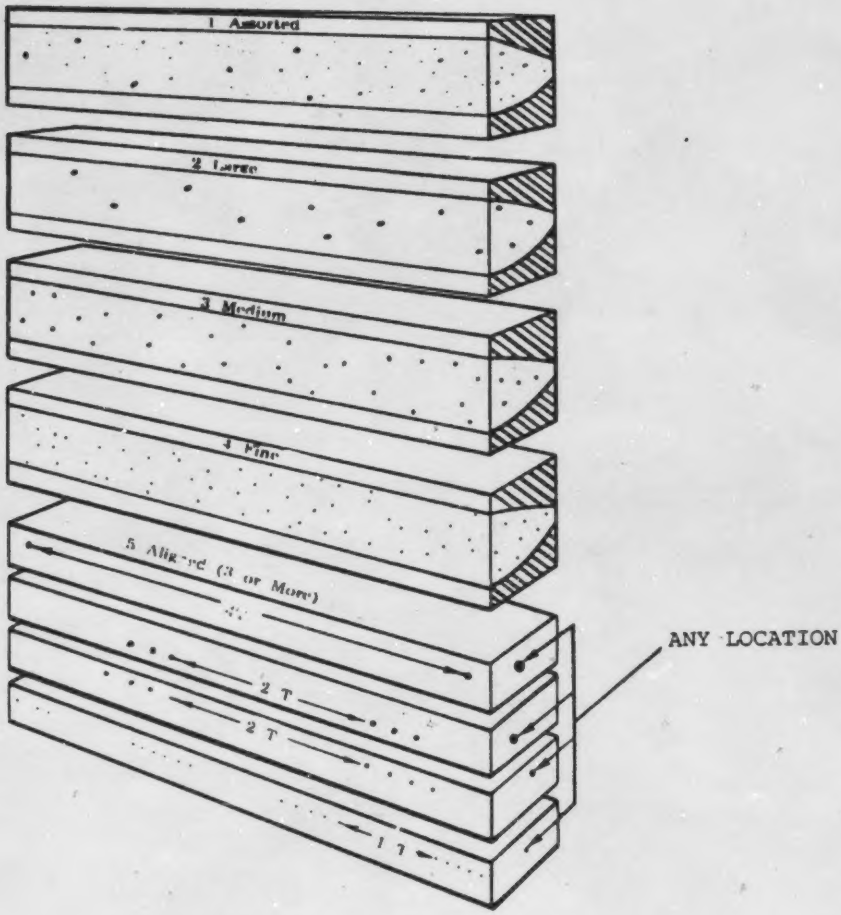
ASME Porosity Criteria

Much of the pressure piping in nuclear power plants which are now in operation was fabricated and tested in accordance with USAS Code for Pressure Piping, B31.7, "Nuclear Power Piping". Appendix B of the standard specifies the requirements for nondestructive examinations, and includes the following acceptance standards for weld radiography:

- USAS B31.7, Paragraph B-1-140 Acceptance Standards - Unacceptable welds, unless the defects are removed and the weld repaired, are those sections of welds that are shown by radiography to have:

1. any type of crack or zone of incomplete fusion or penetration;
2. any elongated inclusion, such as slag or tungsten, that has a length greater than 1/4 inch for t up to 3/4 inch inclusive, 1/3 t for over 3/4 inch to 2-1/4 inch inclusive, and 3/4 inch for t over 2-1/4 inch;
3. any group of inclusions in line that have an aggregated length greater than t in a length of 12 t except when the distance between the successive imperfections exceeds 6 L, where L is the length of the longest imperfection in the group; and
4. porposity in excess of that shown as acceptable by the porosity standards given in Appendix IV in Section III of the ASME Boiler and Pressure Vessel Code.

The American Petroleum Institute (API) publishes standards for pipeline fabrication and welding. The API standards include sketches and measurements to describe the severity and acceptability of defects in welds. Figure 26-7-7, API Acceptance Standard for Porosity in Pipeline Welds, is typical of the standards and sketches produced by that organization.


1 Assorted
2 Large
3 Medium
4 Fine
5 Aligned (3 or More)
4T
2 T
2 T
1 T
ANY LOCATION

WALL THICKNESS
OVER ½" to 1-½"

MAXIMUM DISTRIBUTION
OF GAS POCKETS

Figure 26-7-7 A.P.I. Acceptance Standard for Porosity in Pipeline Welds

Many other standards are also used for radiographic examination work, including military standards and standards developed by manufacturers. It is important that all applicable procedure standards be available to the radiographer before he proceeds with an inspection, and that appropriate acceptance standards have been established and are available for reference.

EVALUATION OF RADIOGRAPHS

A discontinuity detected by radiography is meaningless unless compared to a known conditioner standard, and evaluated for acceptance or rejection. Acceptance standards define the radiographic appearance of least acceptable conditions. Specimen evaluation, then, consists of comparing the interpreted image on the film with the least acceptable condition in terms of the type, quantity and severity level of the discontinuities that are found, and making a judgement to accept or reject the specimen.

The main characteristics of a discontinuity, e.g., type, specific shape, size, orientation and location, determine its overall effect on a part. Type and location govern relative importance; specific shape influences stress concentration; flaw size and orientation determine the effect on nominal stress. Each of these characteristics should be identified for each discontinuity detected, and the resulting information compared to the acceptance standard.

The examination of the finished radiograph should be made under conditions that favor the best visibility of detail - an area with subdued lighting to minimize distracing reflections from the viewing surface.

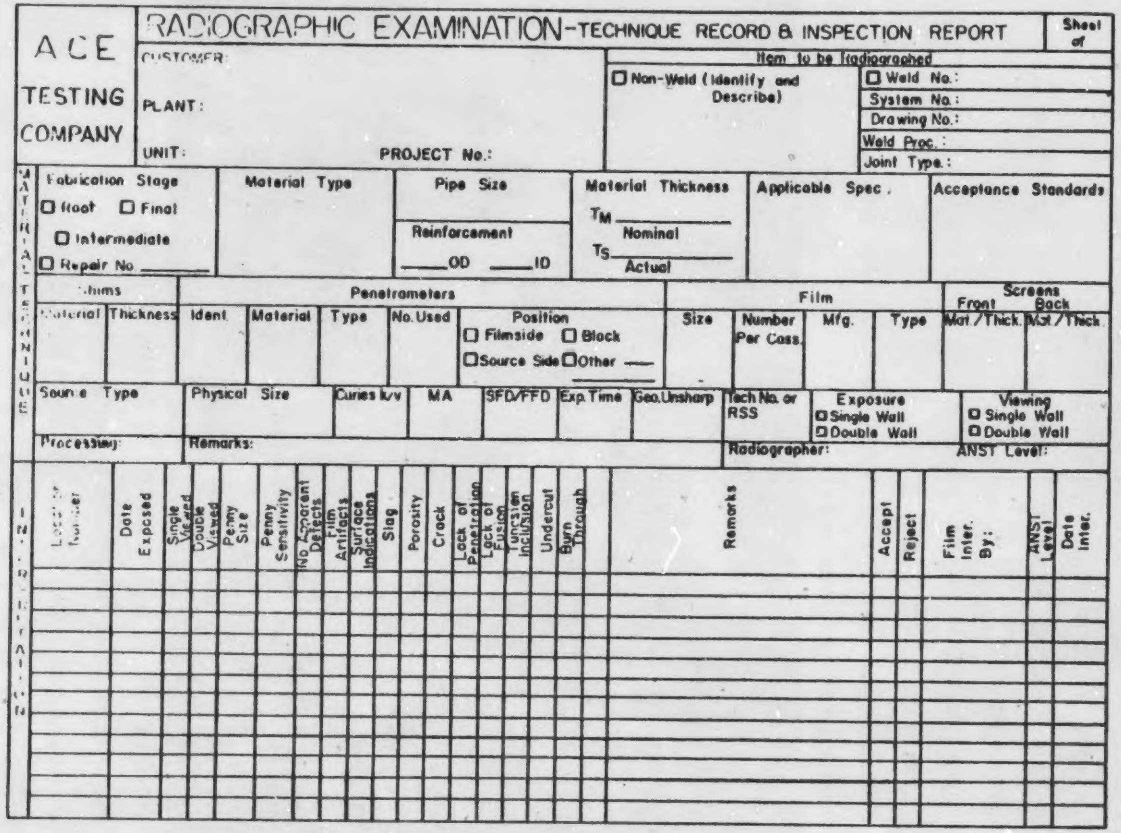
Most radiographic interpretation is conducted on film, viewed as negative images. An illuminator must be used to provide light of an intensity that will illuminate the areas of interest in the radiograph and be diffused evenly over the entire viewing area. For viewing industrial radiographs of moderate density (up to a value of about 2.0), an illuminator incorporating several fluorescent tubes is adequate. For high density films, however, a high-intensity illuminator must be used. This type provides variable controlled light which allows viewing of densities of 4.0 or even higher.

To see the finest detail in a radiograph, the illuminator should be masked to eliminate the glare of bright light at the edges of the film or transmitted through areas of low density. Some illuminators are equipped with adjustable diaphragm-type masks or metal-slide masks, but sheets of thin cardboard or opaque paper can be used as effectively to shield unwanted light from the observer.

PROCEDURES AND REPORTS

For most industrial radiography applications and particularly in critical industries where operations can effect the health and safety of the general public, such as nuclear power plants, examinations must be conducted in accordance with written procedures. Procedures are developed by the user or the testing agency and cover all aspects of the work.

When the specimen is radiographed, all appropriate information about radiographic technique should be recorded on a technique record form such as that shown in Figure 26-7-8. The form shown is a dual-purpose form, e.g., for recording material technique information and film interpre-



ACE TESTING COMPANY

RADIOGRAPHIC EXAMINATION-TECHNIQUE RECORD & INSPECTION REPORT

Sheet of

CUSTOMER:

PLANT:

UNIT: PROJECT No.:

Item to be Radiographed

☐ Non-Weld (Identify and Describe)

☐ Weld No.:

System No.:

Drawing No.:

Weld Proc.:

Joint Type.:

MATERIAL TECHNIQUE

Fabrication Stage

☐ Root ☐ Final

☐ Intermediate

☐ Repair No ______

Material Type

Pipe Size

Reinforcement

____OD ____ID

Material Thickness

T_M ______ Nominal

T_S ______ Actual

Applicable Spec.

Acceptance Standards

Films: Material | Thickness

Penetrameters: Ident. | Material | Type | No. Used | Position ☐ Filmside ☐ Block ☐ Source Side ☐ Other ___

Film: Size | Number Per Cass. | Mfg. | Type

Screens: Front Mat./Thick. | Back Mat./Thick.

Source Type | Physical Size | Curies kv | MA | SFD/FFD | Exp. Time | Geo. Unsharp | Tech No. or RSS

Exposure ☐ Single Wall ☐ Double Wall

Viewing ☐ Single Wall ☐ Double Wall

Processing:

Remarks:

Radiographer:

ANST Level:

INTERPRETATION

Location Number	Date Exposed	Single Viewed	Double Viewed	Penny Size	Penny Sensitivity	No Apparent Defects	Film Artifacts	Surface Indications	Slag	Porosity	Crack	Lack of Penetration	Lack of Fusion	Tungsten Inclusion	Undercut	Burn Through		Remarks	Accept	Reject	Film Inter. By:	ANST Level	Date Inter.

Figure 26-7-8 Radiographic Examination Report Form

tation information and results. The technique information is necessary for the interpreter so that it may be determined if the radiographic technique was adequate prior to actual discontinuity interpretation and reporting. As a minimum, the technique information should include:

- X-ray-source energy (tube voltage) or type of radioisotope
- Tube current in milliamperes, or radioisotope-source strength in curies
- Focal-spot size of x-ray source or physical size of radioisotope source
- Exposure time
- Type of film (brand identification)
- Source-to-film distance
- Type and thickness of screens
- Description of filters, masks and diaphragms
- Viewing direction and method of marking
- Description and location of penetrameters
- Description (sketch) and major dimensions of test piece

A sketch of the shooting arrangement can be drawn on the back of the form, or on an attached sheet.

When the film is read and evaluated by the interpreter, the following information should be recorded on the report:

- Film Identification
- Date Exposed
- Double or Single Film Viewing
- Penetrameter Size and Sensivity
- Evaluation of Film Artifacts, if present
- Identification of Discontinuities, such as:
  (1) Surface Indications
  (2) Slag
  (3) Porosity
  (4) Inclusions

(5) Crack
(6) Lack of Penetration
(7) Undercut
(8) Burn-Through

- Disposition (Accept/Reject)
- Interpreters Name, Qualification Level, Date

The disposition of the examination results is usually very important, and specimen accept or reject decisions should be reported immediately. In many instances, delays in forwarding examination reports can cause costly delays in subsequent operations, whether they be in manufacturing, construction, maintenance or repair work.

EXERCISES

1. Explain why a discontinuity is not necessarily a rejectable defect.
2. Briefly discuss how a crack can be caused in a material.
3. Are gas holes always open to the surface? Explain.
4. Why is it desirable to visually inspect a part even if it is going to be radiographed?
5. Can inadequate or rapid cooling of a weld metal result in a slag entrapment? Explain.
6. How would the lack of penetration in a weld appear in a radiograph?
7. Do propagating discontinuities usually render a part unacceptable?

8. How does excess metal in areas of the surface of a specimen appear on a radiograph?
9. Briefly discuss the characteristics of a discontinuity.
10. What can the radiographic film reader use as a basis of comparison to determine the acceptability of a specimen?
11. Discuss the necessary condition(s) required for viewing high density films successfully.
12. For each of the welds shown in the procedures section of this module evaluate the weld to the appropriate ASME porosity chart and table, and if not acceptable, state the reason for the rejection.
13. For each of the radiographs of pipe welds described in the procedures section, evaluate each weld to the requirements of USAS Appendix B (B 31.7), stating the reason for rejection if the weld isn't acceptable.
14. Obtain samples of both acceptable and rejected pipe welds and castings with radiographs of each and apply the appropriate ASME, ASTM, and USAS acceptance standards to evaluate if each of the parts is acceptable.

MATERIALS

1. ASME Boiler and Pressure Vessel Code ANSI/ASME Volume V, Article 2, Radiographic Examination.
2. American Society for Testing and Materials, Recommended Practice for Radiographic Testing (E 94)
3. USAS Code for Pressure Piping Appendix B (B 31.7) "Nuclear Power Piping."

4. Samples of acceptable and rejected piping welds and radiographs of each.
5. Samples of acceptable and rejected castings and radiographs of each.

PROCEDURES

1. For each of the following welds shown below, evaluate to the appropriate ASME porosity chart and table, and, if not acceptable, state the reason for rejection.

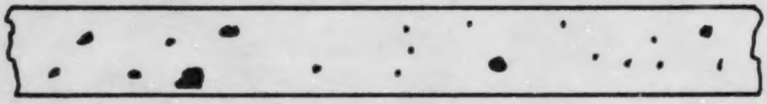
2. For each of the radiographs of piping welds described below, evaluate to the requirements of USAS B31.7, stating the reason for rejection if not acceptable.

Specimen 1

Material: 4" carbon steel pipe, 3/8" wall thickness
Indications: (a) 1/2" zone of incomplete fusion
(b) slag inclusion approximately 3/16" long
(c) no cracks or porosity

Accept ______________
Reject ______________
Reason ________________________________

SPECIMEN 1



Material t = 3/8"

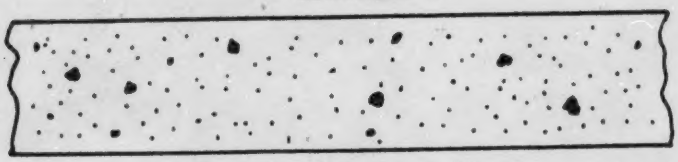
ACCEPT ______________

REJECT ______________

REASON ______________

____

SPECIMEN 2



Material t - 1-½"

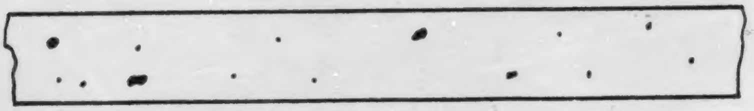
ACCEPT ______________

REJECT ______________

REASON ______________

____

SPECIMEN 3



Material t = ½"

ACCEPT ______________

REJECT ______________

REASON ______________

____

Specimen 2

Material: 2" stainless steel pipe 1/4" wall thickness

Indications: (a) small surface cracks in cover pass
(b) no porosity
(c) tungsten inclusion, 1/8" long

Accept ______________
Reject ______________
Reason _________________________________

Specimen 3

Material: 6" stainless steel pipe, 1/2" wall thickness

Indication: (a) small amount of porosity (acceptable to ASME Section III, Appendix IV)
(b) group of tungsten inclusions 7/16: long in aggregate length of 6", each less less than 1/16" long
(c) one elongated inclusion, length 3/16", not in line

Accept ____________
Reject ____________
Reason _________________________________

3. Using the appropriate standards as given in the Materials section of this module, examine the piping welds and their associated radiographs to evaluate those which are acceptable or unacceptable.

4. Using the required standards, examine the samples of castings and their associated radiographs as listed in the Materials section of this module to determine which are acceptable.

DATA TABLE

None.

REFERENCE MATERIALS

Eastman Kodak Company. Radiography in Modern Industry, 1969

McGonnagle, Warren J., Nondestructive Testing, New York: McGraw Hill Book Company

Metals Handbook, Volume 11, Nondestructive Inspection and Quality Control, American Society of Metals

McMaster, Robert C. (ed.), Nondestructive Testing Handbook, New York: The Ronald Press Company

Omerman, Ralph T., Basic Concepts of Nuclear Chemistry, New York: Reinhold Publishing Corporation

ASME Boiler and Pressure Vessel Code an American National Standard ANSI/ASME BPV-V, Article 2 Radiographic Examination

American Society for Testing and Materials (ASTM), Recommended Practice for Radiographic Testing (E 94)

USAS Code for Pressure Piping, Appendix B, "Nuclear Power Piping"

TEST

Answer the following statements as either true or false:

1. All discontinuities are rejectable defects. _____
2. Cracks are caused by stress perpendicular to the plane of the crack. _____
3. "Hot tears" are considered cracks. _____
4. Gas holes are always open to the surface. _____
5. Porosity is a form of gas holes or inclusions. _____
6. Visual examination of a part is unnecessary when the part is to be radiographed. _____
7. Tungsten inclusions are commonly found in castings. _____
8. Inadequate heat or rapid cooling of weld metal may result in slag entrapment. _____
9. Weld slag inclusions appear as light, uniformly rounded spots in radiographs. _____
10. Lack of penetration in a weld usually appears as a straight, dark line in the radiograph. _____
11. Tungsten particles from electrodes in the welding process usually melt and blend into the weld metal. _____
12. Gas holes and porosity are common discontinuities found in castings. _____
13. Excess metal in areas of the surface of a specimen appears as light areas on the radiograph thereof. _____
14. Propagating discontinuities usually render a part unacceptable. _____
15. Unfused chaplets occur only in weld fusion zones. _____

Complete the following statements:

16. Three of the distinguishing characteristics of a discontinuity are ________________, ___________________ and ____________________.

17. Radiographic ___________________ are used by the film reader or interpreter as a basis of comparison to determine the _______________ of the specimen.

18. Adequate _______________ must be provided in order to view the areas of interest in a radiograph.

19. __________________ lighting should be provided in the area where film viewing is performed.

20. High density films can be viewed successfully only with ____________________ illuminators.

NUCLEAR TECHNOLOGY

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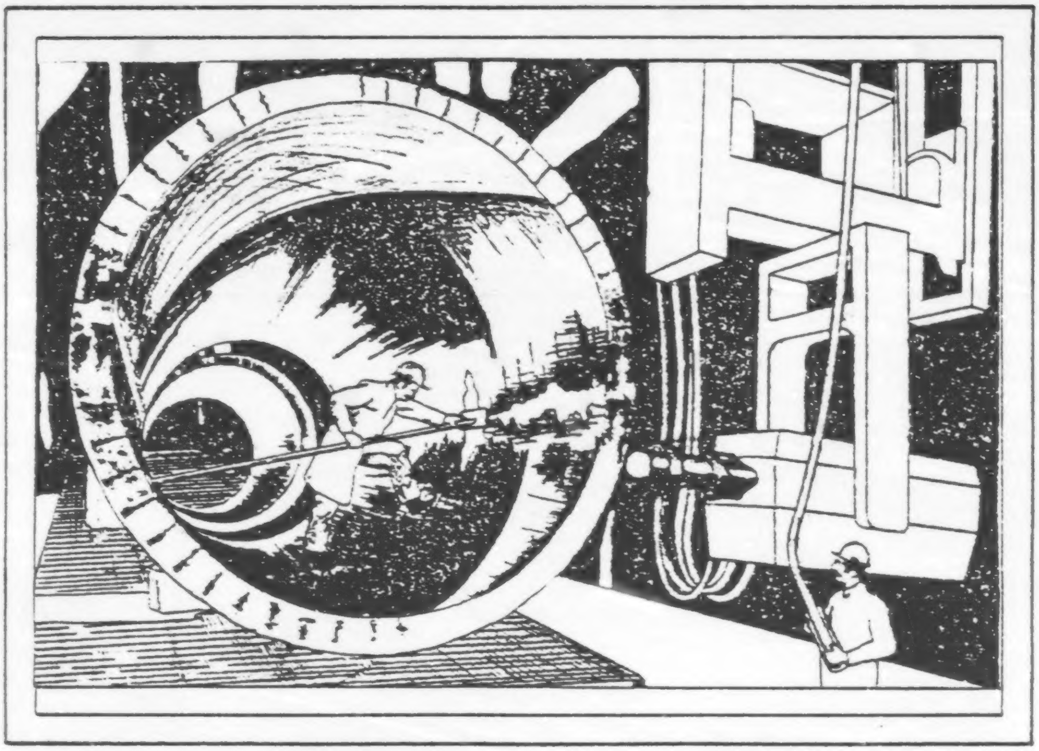
COURSE 26 - NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES I



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4800 LAKEWOOD DRIVE WACO, TEXAS

NUCLEAR TECHNOLOGY SERIES

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for
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